ANNUAL REPORT

OF THE

BOARD OF REGENTS

OF THE

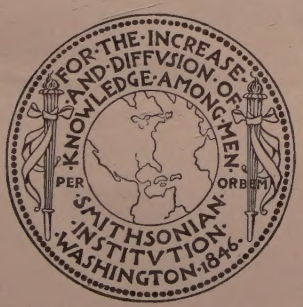
SMITHSONIAN INSTITUTION,

SHOWING

THE OPERATIONS, EXPENDITURES, AND CONDITION OF THE INSTITUTION

FOR

THE YEAR ENDING JUNE 30, 1902.



WASHINGTON:
GOVERNMENT PRINTING OFFICE.
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LETTER

FROM THE

SECRETARY OF THE SMITHSONIAN INSTITUTION,

ACCOMPANYING

The Annual Report of the Board of Regents of the Institution for the year ending June 30, 1902.

SMITHSONIAN INSTITUTION,
Washington, D. C., May 23, 1903.

To the Congress of the United States:

In accordance with section 5593 of the Revised Statutes of the United States, I have the honor, in behalf of the Board of Regents, to submit to Congress the Annual Report of the operations, expenditures, and condition of the Smithsonian Institution for the year ending June 30, 1902.

I have the honor to be, very respectfully, your obedient servant,

S. P. LANGLEY,
Secretary of the Smithsonian Institution.

Hon. WILLIAM P. FRYE,
President pro tempore of the Senate.

ANNUAL REPORT OF THE SMITHSONIAN INSTITUTION FOR THE YEAR ENDING JUNE 30, 1902.

SUBJECTS.

1. Proceedings of the Board of Regents for the session of January 22, 1902.

2. Report of the executive committee, exhibiting the financial affairs of the Institution, including a statement of the Smithson fund, and receipts and expenditures for the year ending June 30, 1902.

3. Annual report of the Secretary, giving an account of the operations and condition of the Institution for the year ending June 30, 1902, with statistics of exchanges, etc.

4. General appendix, comprising a selection of miscellaneous memoirs of interest to collaborators and correspondents of the Institution, teachers, and others engaged in the promotion of knowledge. These memoirs relate chiefly to the calendar year 1902.

CONTENTS.

	Page.
Letter from the Secretary, submitting the Annual Report of the Regents to Congress	III
General subjects of the Annual Report	IV
Contents of the Report	V
List of Plates	VIII
Members *ex officio* of the Establishment	IX
Regents of the Smithsonian Institution	X
PROCEEDINGS OF THE BOARD OF REGENTS.	
Stated meeting January 22, 1902	XI
REPORT OF THE EXECUTIVE COMMITTEE for the year ending June 30, 1902.	
Condition of the fund July 1, 1902	XVII
Receipts and expenditures for the year	XVIII
Appropriation for International Exchanges	XIX
Details of expenditures of same	XIX
Appropriation for American Ethnology	XX
Details of expenditures of same	XXI
Appropriations for the National Museum	XXII
Details of expenditures of same	XXII
Appropriation for Astrophysical Observatory	XLIII
Details of expenditures of same	XLIII
Balance of appropriation for observation of solar eclipse	XLIV
Appropriation for the National Zoological Park	XLIV
Details of expenditures of same	XLIV
Recapitulation	XLIX
General summary	L
ACTS AND RESOLUTIONS OF CONGRESS relative to Smithsonian Institution, etc.	LIII

REPORT OF THE SECRETARY.

THE SMITHSONIAN INSTITUTION	1
The Establishment	1
Board of Regents	2
Organization of Regents	4
Administration	5
Buildings	5
Finances	5
Research	7
Hodgkins fund	7
Naples table	11
Explorations	12
Publications	12
Library	14

THE SMITHSONIAN INSTITUTION—Continued. Page.
Correspondence ... 15
Expositions ... 16
Miscellaneous ... 16
National Museum ... 18
Bureau of American Ethnology ... 20
International Exchanges ... 22
National Zoological Park ... 23
Astrophysical Observatory ... 24
Necrology ... 27
Appendixes:
I. Report on the United States National Museum ... 29
II. Report on the Bureau of American Ethnology ... 39
III. Report on the International Exchange Service ... 58
IV. Report on the National Zoological Park ... 73
V. Report on the Astrophysical Observatory ... 85
VI. Report of the Librarian ... 97
VII. Report of the Editor ... 100
VIII. Report on Pan-American Exposition ... 110

GENERAL APPENDIX.

Recent Aeronautical Progress, and deductions to be drawn therefrom, regarding the future of Aerial Navigation, by Maj. B. F. Baden-Powell ... 121
Some Aeronautical Experiments, by Wilbur Wright ... 133
Stellar Evolution in light of Recent Research, by Prof. George E. Hale ... 149
A New Solar Theory, by Prof. J. Halm ... 165
An Experimental Investigation of the Pressure of Light, by Peter Lebedew ... 177
Comets' Tails, the Corona, and the Aurora Borealis, by Prof. John Cox ... 179
"Good Seeing," by S. P. Langley ... 193
On the Radio-activity of Matter, by Henri Becquerel ... 197
History of Cold and the Absolute Zero, by Prof. James Dewar ... 207
Experimental Phonetics, by Prof. John G. McKendrick ... 241
Wireless Telegraphy—its past and present status and prospects, by William Maver, jr ... 261
Telpherage, by Charles M. Clark ... 275
The Evolution of Petrological Ideas, by J. J. Harris Teall ... 287
Preliminary Report on the Recent Eruption of the Soufrière in St. Vincent, and of a visit to Mont Pelée, in Martinique, by Tempest Anderson and John S. Flett ... 309
Volcanic Eruptions on Martinique and St. Vincent, by Israel C. Russell ... 331
The Progress of Geographical Knowledge, by Col. Sir T. H. Holdich ... 351
The Discovery of the Future, by H. G. Wells ... 375
The Life of Matter, by A. Dastre ... 393
The Craniology of Man and Anthropoid Apes, by N. C. Macnamara ... 431
The Baoussé-Roussé Explorations: Study of a new human type by M. Verneau, by Albert Gaudry ... 451
Fossil Human Remains found near Lansing, Kansas, by W. H. Holmes ... 455
The Wild Tribes of the Malay Peninsula, by W. W. Skeat ... 463
The Pygmies of the Great Congo Forest, by Sir Harry H. Johnston ... 479
Guam and its People, by W. E. Safford ... 493
Oriental Elements of Culture in the Occident, by Dr. Georg Jacob ... 509

Page.
The Nile Reservoir Dam at Assuân, by Thomas H. Means 531
The Panama Route for a Ship Canal, by William H. Burr 537
The Problems of Heredity and their Solution, by W. Bateson 559
The Morphological Method and Recent Progress in Zoology, by Prof. G. B. Howes 581
Coral, by Dr. Louis Roule 609
Reindeer in Alaska, by Gilbert H. Grosvenor 613
A Marine University, by W. K. Gregory 625
John Wesley Powell, by G. K. Gilbert 633
Rudolph Virchow, by Oscar Israel 641

LIST OF PLATES.

	Page.
SECRETARY'S REPORT:	
Plates I, II	30
Plate III	49
Plate IV	60
Plate V	74
Plate VI	85
Plates VII, VIII	86
Plate IX	90
AERONAUTICS (WRIGHT):	
Plates I, II	138
Plates III, IV	142
STELLAR EVOLUTION (HALE):	
Plates I, II	150
Plates III, IV	152
Plates V, VI	154
Plates VII, VIII	156
Plates IX, X	160
Plate XI	162
GOOD SEEING (LANGLEY):	
Plate I	194
RADIO-ACTIVITY (BECQUEREL):	
Plates I, II	198
Plates III, IV	200
Plates V, VI	202
Plate VII	204
WIRELESS TELEGRAPHY (MAVER):	
Plates I, II	262
Plates III, IV	268
TELPHERAGE (CLARK):	
Plate I	275
Plates II, III, IV, V	276
Plates VI, VII	280
Plates VIII, IX, X, XI, XII, XIII	286
THE SOUFRIÈRE (ANDERSON AND FLETT):	
Plates I, II, III	330
MARTINIQUE (RUSSELL):	
Plate I	331
Plates II, III	334
Plates IV, V	336
MARTINIQUE (RUSSELL)—Cont'd.	
Plates VI, VII	338
Plates VIII, IX	340
Plates X, XI	342
CRANIOLOGY OF MAN AND APES (MACNAMARA):	
Plates I, II, III, IV, V, VI	450
BAOUSSÉ-ROUSSÉE (GAUDRY):	
Plates I, II	452
FOSSIL HUMAN REMAINS (HOLMES):	
Plates I, II	456
Plate III	458
WILD TRIBES OF MALAY (SKEAT):	
Plates I, II	464
GUAM AND ITS PEOPLE (SAFFORD):	
Plates I, II	494
Plates III, IV	496
Plates V, VI	498
Plates VII, VIII	500
Plates IX, X	504
Plates XI, XII	506
NILE RESERVOIR DAM (MEANS):	
Plates I, II	532
Plates III, IV, V, VI	534
PANAMA ROUTE (BURR):	
Plates I, II	538
CORAL (ROUFE):	
Plates I, II	610
REINDEER IN ALASKA (GROSVENOR):	
Plates I, II	614
Plates III, IV	616
Plates V, VI, VII, VIII	618
Plates IX, X	620
Plate XI	622
MARINE UNIVERSITY (GREGORY):	
Plates I, II	626
Plate III	630
J. W. POWELL (GILBERT):	
Plate I	633
RUDOLPH VIRCHOW (ISRAEL):	
Plate I	641

THE SMITHSONIAN INSTITUTION.

MEMBERS EX OFFICIO OF THE "ESTABLISHMENT."

THEODORE ROOSEVELT, President of the United States.
(Vacancy), Vice-President of the United States.
MELVILLE W. FULLER, Chief Justice of the United States.
JOHN HAY, Secretary of State.
LESLIE M. SHAW, Secretary of the Treasury.
ELIHU ROOT, Secretary of War.
PHILANDER C. KNOX, Attorney-General.
HENRY C. PAYNE, Postmaster-General.
WILLIAM H. MOODY, Secretary of the Navy.
ETHAN ALLEN HITCHCOCK, Secretary of the Interior.
JAMES WILSON, Secretary of Agriculture.

REGENTS OF THE INSTITUTION.

(List given on the following page.)

OFFICERS OF THE INSTITUTION.

SAMUEL P. LANGLEY, *Secretary.*

Director of the Institution, and Keeper of the U. S. National Museum.

RICHARD RATHBUN, *Assistant Secretary.*

REGENTS OF THE SMITHSONIAN INSTITUTION.

By the organizing act approved August 10, 1846 (Revised Statutes, Title LXXIII, section 5580), "The business of the Institution shall be conducted at the city of Washington by a Board of Regents, named the Regents of the Smithsonian Institution, to be composed of the Vice-President, the Chief Justice of the United States, three members of the Senate, and three members of the House of Representatives, together with six other persons, other than members of Congress, two of whom shall be resident in the city of Washington and the other four shall be inhabitants of some State, but no two of the same State.

REGENTS FOR THE YEAR ENDING JUNE 30, 1902.

The Chief Justice of the United States:
MELVILLE W. FULLER, elected Chancellor and President of the Board, January 9, 1889.
The Vice-President of the United States:
THEODORE ROOSEVELT (to Sept. 14, 1901, when he became President).

United States Senators:	Term expires
SHELBY M. CULLOM (appointed Mar. 24, 1885, Mar. 28, 1889, Dec. 18, 1895, and Mar. 7, 1901)	Mar. 3, 1907
ORVILLE H. PLATT (appointed Jan. 18, 1899)	Mar. 3, 1903
FRANCIS M. COCKRELL (appointed Mar. 7, 1901)	Mar. 3, 1905
Members of the House of Representatives:	
ROBERT R. HITT (appointed Aug. 11, 1893, Jan. 4, 1894, Dec. 20, 1895, Dec. 22, 1897, Jan. 4, 1900, and Dec. 13, 1901)	Dec. 23, 1903
ROBERT ADAMS, JR. (appointed Dec. 20, 1895, Dec. 22, 1897, Jan. 4, 1900, and Dec. 13, 1901)	Dec. 23, 1903
HUGH A. DINSMORE (appointed Jan. 4, 1900, and Dec. 13, 1901)	Dec. 23, 1903
Citizens of a State:	
JAMES B. ANGELL, of Michigan (appointed Jan. 19, 1887, Jan. 9, 1893, and Jan. 24, 1899)	Jan. 24, 1905
ANDREW D. WHITE, of New York (appointed Feb. 15, 1888, Mar. 19, 1894, and June 2, 1900)	June 2, 1906
RICHARD OLNEY, of Massachusetts (appointed Jan. 24, 1900)	Jan. 24, 1906
Citizens of Washington city:	
JOHN B. HENDERSON (appointed Jan. 26, 1892, and Jan. 24, 1898)	Jan. 24, 1904
ALEXANDER GRAHAM BELL (appointed Jan. 24, 1898)	Jan. 24, 1904
GEORGE GRAY (appointed Jan. 14, 1901)	Jan. 14, 1907

Executive Committee of the Board of Regents.

J. B. HENDERSON, *Chairman.* ALEXANDER GRAHAM BELL.
ROBERT R. HITT.

PROCEEDINGS OF THE BOARD OF REGENTS AT THE ANNUAL MEETING HELD JANUARY 22, 1902.

In accordance with a resolution of the Board of Regents, adopted January 8, 1890, by which its annual meeting occurs on the fourth Wednesday of each year, the Board met to-day at 10 o'clock a. m.

Present: Chief Justice Fuller, (Chancellor), in the chair; the Hon. William P. Frye; the Hon. S. M. Cullom; the Hon. O. H. Platt; the Hon. F. M. Cockrell; the Hon. Robert Adams, jr.; the Hon. Hugh A. Dinsmore; Dr. James B. Angell; the Hon. John B. Henderson; the Hon. George Gray; Dr. A. Graham Bell; the Hon. Richard Olney, and the Secretary, Mr. S. P. Langley.

EXCUSES FOR NONATTENDANCE.

The Secretary explained that Mr. Hitt was unable to be present owing to temporary indisposition, and that Dr. Andrew D. White was in Europe.

At the suggestion of the Chancellor, the Secretary read the minutes of the last meeting in abstract, and there being no objection, they were declared approved.

APPOINTMENT OF REGENTS.

The Secretary stated that Vice-President Roosevelt had been ex-officio a member of the Board, but that by reason of his succession on September 14, 1901, to the Presidency through the death of President McKinley, his membership upon the Board had ceased, and he had become the presiding officer of the Institution. In accordance with precedent, an invitation had been extended to the President pro tempore of the Senate, the Hon. William P. Frye, to attend the meeting in place of the Vice-President. The Secretary announced the appointment of Senator Francis M. Cockrell, of Missouri, to succeed Senator Lindsay, and the reappointment of Senator S. M. Cullom and of Representatives R. R. Hitt, Robert Adams, jr., and Hugh A. Dinsmore, whose terms had expired.

The Secretary read a letter from Mrs. W. L. Wilson expressing her thanks for the engrossed resolutions adopted by the Board at the last meeting on the death of her husband, Dr. William Lyne Wilson.

The Secretary presented his report of the operations of the Institution for the fiscal year ending June 30, 1901, which was accepted, and in which he invited the Board's attention to the statements concerning the National Zoological Park, the International Exchange Bureau, and the other interests under their charge. He spoke particularly with regard to the crowded condition of the National Museum, the need for additional space for the exhibition and care of the increasing collections, and the need of special action to secure it.

After discussion, the following resolution was adopted:

Resolved, That a committee consisting of six members of this Board be appointed by the Chancellor, whose duty it shall be to represent to Congress the pressing necessity of additional room for the proper exhibition of specimens belonging to the National Museum, and of additional appropriations to carry on the work of the Museum.

The Chancellor appointed as members of this committee, Senators Platt, Cullom, and Cockrell, and Representatives Hitt, Adams, and Dinsmore.

Senator Henderson, as chairman of the executive committee, presented the annual report of that committee for the fiscal year ending June 30, 1901.

On motion, the report was adopted.

REPORT OF THE PERMANENT COMMITTEE.

Senator Henderson, chairman of the permanent committee, made the following statement:

THE HODGKINS FUND.

The Regents will remember that in addition to the sum of approximately $208,000 already deposited in the general fund constituted by the Hodgkins bequest, and first-class bonds of a present market value of perhaps $42,000, already in the custody of the Institution, a residual sum of about $9,000 is still in the hands of the executor of the estate, and is deposited with the New York Insurance and Trust Company of New York City, by order of court, awaiting the decision of certain suits in which the liability of the estate of Mr. Hodgkins, on account of a warranty of title by him in the transfer of certain property in New York City, is in question.

One of the two small properties in Elizabeth, N. J., derived by the Institution through the Hodgkins bequest, was sold during the year, with the approval of the permanent committee, for $600. The remaining property, consisting of a single house and lot, the value of which is estimated at $1,000, has been continued in the care of the real estate agents in Elizabeth, who have been charged with its management for several years. It is, in the opinion of the permanent committee, desirable that this small holding be likewise disposed of whenever an opportunity for its sale at a fair price is presented.

THE AVERY FUND.

The properties received by the Institution from the Avery bequest have been estimated to be worth $26,000. They are mostly unimproved, and yield a revenue of only about $500 a year. Mrs. Julia N Chase (formerly Miss Julia N. Avery) presented a claim for $636 against the Institution on account of a slight encroachment

by one of the properties on the adjoining premises owned by her. After some negotiation the matter was adjusted by the payment to Mrs. Chase of the sum of $220 and the conveyance of the narrow strip of land in question to the Institution. The committee recommends that in case a fair price be offered for any of these properties the Institution dispose of its holdings.

THE ANDREWS BEQUEST.

At the last annual meeting of the Regents the specification in the will of Wallace C. Andrews, deceased, naming the Institution as the residuary legatee of his estate, contingent on the failure of a bequest for founding at Willoughby, Ohio, an institution for the free education of girls, was set forth at some length. It appears that after specific bequests amounting to $500,000 have been executed a residuum of at least $1,000,000 will remain. Mr. Hackett, counsel for the Institution, is in communication with the counsel for the executor, and Edmund Wetmore, Esq., a member of the bar of the State of New York, has also been retained to look after the interests of the Institution in the matter. The following extract is quoted from Mr. Hackett's report on the present status of the bequest, so far as it concerns the Institution:

"As already stated, the scheme of founding a young ladies' school in Ohio is likely to prove impracticable. It is significant that, as yet, no one in Ohio has taken any steps to secure the payment of the legacy. Under the terms of the will certain officials, including the governor of the State, are made trustees to administer this fund. The mayor of the little town (Willoughby) is of the board. This officer has inquired of Mr. Hawes as to what has been done in the premises, but no active interest is exhibited in Ohio for the reason that there is no one who may be said to have an interest in the success of the scheme."

It is hoped that before long an amicable understanding may be had for obtaining a ruling of the court as a guide to the executor in carrying out the provisions of the will.

THE SPRAGUE BEQUEST.

The attention of the Regents was called at their last meeting to the provisions of the will of Mr. Joseph White Sprague, who, after bequeathing certain personal effects to relatives, directs the executor, in trust, to convert the personalty into money and to distribute 85 per cent of the income of the entire estate among certain devisees until twenty years after the death of the last of said devisees, when the trust will expire by limitation and all assets in the hands of the trustee will be conveyed to the United States of America in accordance with the following paragraph in the will:

"When the trust herein created expires by limitation, as aforesaid, then all distribution of the income of the trust property is to cease, and said trustee is instructed and directed to assign and make over by proper conveyance all trust property in his possession, whether real or personal, invested or uninvested, to the United States of America, to be held by said United States as a portion of the funds of the Smithsonian Institute, to be known as the 'Sprague fund,' the income of this fund to be used as follows: One-half of said income in each year to be added to the principal. The other half of said income is to be expended, under the direction of the officers of the said Institute, in such manner as will in their judgment best promote the advancement of the physical sciences, either by arranging for the giving of free lectures, on scientific subjects, in different cities and towns of the said United States, or by providing for original scientific research in the laboratory and otherwise, or by the publication of the results of original scientific researches, or by offering, from time to time, rewards or medals, for meritorious discoveries, or by any or all of these methods, as in their judgment may seem best. The half of the gross income thus authorized to be expended annually is to be cumulative, so that the portion of it unexpended during any one year may be expended during any subsequent year or years."

Although the time at which the Institution will derive any profit from the above legacy may reasonably be assumed to be somewhat remote, it is believed, if the newspaper estimate of $200,000 be even approximately accurate, that the amount of the fund which will accrue to the Institution will not be inconsiderable. At present there would seem to be no further duty imposed upon the Institution than to see that the property is accounted for and is held in safe hands.

On motion, the report was accepted.

Senator Henderson, as chairman of the executive committee, presented the following resolution, which was adopted:

Resolved, That the income of the Institution for the fiscal year ending June 30, 1903, be appropriated for the service of the Institution, to be expended by the Secretary, with the advice of the executive committee, with full discretion on the part of the Secretary as to items.

REMOVAL OF SMITHSON'S REMAINS.

The Secretary recalled to the Board the resolution adopted by it at the last meeting with regard to the removal of the remains of James Smithson. The wishes of the Board were communicated to one of the officers of the English church at Genoa, Mr. E. A. Le Mesurier, who, under date of December 23, 1901, replied in part as follows:

* * * * * * *

You are aware that our hope is eventually to obtain for our countrymen a separate burying place which by an easy, and I may say obvious, arrangement might be made to give shelter not merely to British subjects, but to American also. I regret to say, however, that I see no chance for the present of this most desirable consummation, as the authorities (apparently in consequence of the difficulty of finding an alternative site) have withdrawn their offer of providing us with a fresh cemetery if we allowed them to transfer at once all remains from San Benigno, where your founder rests. The present policy of the authorities is presumably to let things remain as they are until the time comes (three years or so hence) when the law of public utility will strengthen their hands as to taking possession of the San Benigno ground, of course under the obligation of transporting the remains elsewhere, which would in all probability mean a portion of the general Protestant Cemetery and not a separate place of interment. When the time for the transfer approaches it will be obviously expedient to apply to the British ambassador at Rome (backed up as we are confident will be the case by the friendly offices of the representative of the United States) to put the case before the Italian Government, so that the local authorities may be enjoined to carry out the process with all due reverence and if possible (as it ought to be possible) to a specially reserved new cemetery. Our consul is most fully alive to the importance of diplomatic support and will take the initiative in due course.

Mr. Bell here said that he would like very much to have in the record that he had presented to the Board at the last meeting his strong feeling that the remains of Smithson should be brought to this country.

The Secretary informed Mr. Bell that his remarks were now on the written record.

SANTA FE PALACE.

The Secretary said that the governor of New Mexico had offered to transfer to the Institution an ancient Spanish palace in Santa Fe, on condition that it be maintained, without cost to the State, as a museum of the archæology of the Southwest. After discussion the Board decided that it was inadvisable to accept the proposition.

THE CARNEGIE INSTITUTION.

The Secretary said that since the foundation of the Smithsonian Institution there had perhaps occurred no event of more importance to it than the foundation of a new institution—the Carnegie Institution—whose declared aims and general purposes were nearly those which the Institution has hitherto considered its own. Mr. Carnegie invited the Secretary of the Smithsonian to become a member of the board of trustees for the management of this fund, in the following letter:

DECEMBER 27, 1901.

DEAR SIR: I am about to transfer ten millions of 5 per cent bonds to a body of trustees for the purposes described in the inclosed paper. A list of the trustees selected is also inclosed.

It will be a source of much pleasure to me if you will kindly consent to serve.

Truly yours,

ANDREW CARNEGIE.

THE SECRETARY OF THE SMITHSONIAN INSTITUTION.

The letter was accompanied by a list of the trustees and by a statement of the considerations which led to the establishment of the foundation. The Secretary read the articles of incorporation of the new institution, and stated that after conference with the Chancellor and the chairman of the executive committee, he had accepted the trusteeship in the following terms, conditionally on the approval of the board:

DECEMBER 31, 1901.

DEAR SIR: I beg to acknowledge the receipt of your communication of the 27th instant, with the accompanying papers outlining the general purpose of an institution or establishment which you propose to found in the city of Washington for the encouragement of research and kindred purposes, and also inclosing a list of proposed trustees, in which you are good enough to name the Secretary of the Smithsonian Institution as an ex officio member.

It will give me, personally, great pleasure, with the consent of the Regents, to accept membership upon this board, and I desire to express my sense of warm recognition of the large purposes which have inspired you to make this noble benefaction. I accept such membership in the absence of knowledge as to details, but in the full confidence of a sympathy with your general purpose.

Very respectfully, yours,

S. P. LANGLEY,
Secretary.

ANDREW CARNEGIE, Esq.,
No. 5 West Fifty-fifth Street, New York City.

He then stated certain considerations with regard to the relationship of the Smithsonian Institution to the Carnegie Institution, and asked for an expression of the opinions of the Regents for his instruction. After discussion it was announced as the sense of the Board that the Secretary should accept the trusteeship unfettered by instructions.

PUBLICATIONS OF THE INSTITUTION.

The Secretary called the attention of the Board to the exhibition of Reports and other publications which had been issued by the Institution during the year.

The Secretary then spoke of the affairs of the Bureau of Ethnology, and of the Astrophysical Observatory, whose first volume of the Annals he exhibited. With regard to the Observatory, the Secretary said further that Congress had asked for a report of the appropriations granted it and of the results obtained. Such a report had been submitted at the beginning of the session, and had been ordered printed. It included the Annals above referred to, and he had been enabled to add a number of commendatory letters from eminent men of science, such as Sir George Stokes, Lord Rayleigh, Lord Kelvin, Sir William Huggins, Sir Robert Ball, Prof. Simon Newcomb, Prof. E. C. Pickering, Prof. G. E. Hale, and others.

There being no further business to come before the Board, on motion the meeting adjourned.

REPORT OF THE EXECUTIVE COMMITTEE OF THE BOARD OF REGENTS OF THE SMITHSONIAN INSTITUTION

FOR THE YEAR ENDING JUNE 30, 1902.

To the Board of Regents of the Smithsonian Institution:

Your Executive Committee respectfully submits the following report in relation to the funds of the Institution, the appropriations by Congress, and the receipts and expenditures for the Smithsonian Institution, the U. S. National Museum, the International Exchanges, the Bureau of Ethnology, the National Zoological Park, and the Astrophysical Observatory for the year ending June 30, 1902, and balances of former years:

SMITHSONIAN INSTITUTION.

Condition of the Fund July 1, 1902.

The amount of the bequest of James Smithson deposited in the Treasury of the United States, according to act of Congress of August 10, 1846, was $515,169. To this was added by authority of Congress, February 8, 1867, the residuary legacy of Smithson, savings from income, and other sources, to the amount of $134,831.

To this also have been added a bequest from James Hamilton, of Pennsylvania, of $1,000; a bequest of Dr. Simeon Habel, of New York, of $500; the proceeds of the sale of Virginia bonds, $51,500; a gift from Thomas G. Hodgkins, of New York, of $200,000 and $8,000, being a portion of the residuary legacy of Thomas G. Hodgkins, and $1,000, the accumulated interest on the Hamilton bequest, making in all, as the permanent fund, $912,000.

The Institution also holds the additional sum of $42,000, received upon the death of Thomas G. Hodgkins, in registered West Shore Railroad 4 per cent bonds, which were, by order of this committee, under date of May 18, 1894, placed in the hands of the Secretary of the Institution, to be held by him subject to the conditions of said order.

Statement of receipts and expenditures from July 1, 1901, to June 30, 1902.

RECEIPTS.

Cash on hand July 1, 1901		$83,963.26	
Interest on fund July 1, 1901	$27,360.00		
Interest on fund Jan. 1, 1902	27,360.00		
		54,720.00	
Interest to Jan. 1, 1902, on West Shore bonds		1,680.00	
			$140,363.26
Cash from sales of publications		301.85	
Cash from repayments, freight, etc		10,109.24	
			10,411.09
Total receipts			150,774.35

EXPENDITURES.

Building:			
Repairs, care, and improvements	$8,311.67		
Furniture and fixtures	2,604.32		
		$10,915.99	
General expenses:			
Postage and telegraph	185.36		
Stationery	1,128.03		
Incidentals (fuel, gas, etc.)	4,851.29		
Library (books, periodicals, etc.)	2,593.22		
Salaries[a]	23,144.93		
Gallery of art	127.43		
Meetings	269.49		
		32,299.75	
Publications and researches:			
Smithsonian contributions	16.00		
Miscelloneous collections	2,250.15		
Reports	2,548.05		
Researches	5,497.63		
Apparatus	1,173.29		
Hodgkins fund	4,928.52		
Bell and Kidder fund	5,565.75		
		21,979.39	
Literary and scientific exchanges		4,458.31	
			69,653.44
Balance unexpended June 30, 1902			81,120,91

The cash received from the sale of publications, from repayments, freights, etc., is to be credited to the items of expenditure, as follows:

Smithsonian contributions	$28.70		
Miscellaneous collections	232.49		
Reports	40.66		
		$301.85	
Exchanges		6,463.49	
Incidentals		2,145.75	
Researches		1,500.00	
			$10,411.09

[a] In addition to the above $23,144.93, paid for salaries under general expenses, $11,056.05 were paid for services, viz, $4,036.31 charged to building account, $1,030.50 to furniture and fixtures account, $2,722.38 to researches account, $1,387.62 to library account, $853.78 to apparatus account, and $1,025.46 to Hodgkins-fund account.

The net expenditures of the Institution for the year ending June 30, 1902, were therefore $59,242.35, or $10,411.09 less than the gross expenditures, $69,653.44, as above stated.

All moneys received by the Smithsonian Institution from interest, sales, refunding of moneys temporarily advanced, or otherwise, are deposited with the Treasurer of the United States to the credit of the Secretary of the Institution, and all payments are made by his checks on the Treasurer of the United States.

Your committee also presents the following statements in regard to appropriations and expenditures for objects intrusted by Congress to the care of the Smithsonian Institution:

Detailed statement of disbursements from appropriations committed by Congress to the care of the Smithsonian Institution for the fiscal year ending June 30, 1902, and from balances of former years.

INTERNATIONAL EXCHANGES, SMITHSONIAN INSTITUTION, 1902.

RECEIPTS.

Appropriated by Congress for the fiscal year ending June 30, 1902, "for expenses of the system of international exchanges between the United States and foreign countries, under the direction of the Smithsonian Institution, including salaries or compensation of all necessary employees and the purchase of necessary books and periodicals" (sundry civil act, March 3, 1901)	$24,000.00

DISBURSEMENTS.

[From July 1, 1901, to June 30, 1902.]

Salaries or compensation:	
1 acting curator, 12 months, at $225	$2,700.00
1 chief clerk, 12 months, at $183.33	2,199.96
1 clerk, 12 months, at $150	1,800.00
1 clerk, 12 months, at $125	1,500.00
1 clerk, 2 months, at $125	250.00
1 clerk, 12 months, at $108.33	1,299.96
1 clerk, 12 months, at $80	960.00
1 clerk, 12 months, at $50	600.00
1 stenographer, 12 months, at $100	1,200.00
1 packer, 12 months, at $55	660.00
1 workman, 12 months, at $55	660.00
1 skilled laborer, 1 day, at $2.25	2.25
1 laborer, 12 months, at $45	540.00
1 laborer, 1 day, at $2	2.00
1 laborer, 3½ days, at $1.50	5.25
1 laborer, 3½ days, at $1.50	5.25
1 laborer, 1 day, at $1.50	1.50
1 laborer, 4 days, at $1.50	6.00
1 messenger, 7 months and 11 days, at $35	258.75
1 messenger, 3 months and 15 days, at $30	104.52
1 messenger, 3 months and 15 days, at $25	87.10
1 messenger, 8 months and 5½ days, at $25; 3½ months, at $30	309.44

Salaries or compensation—Continued.		
1 carpenter, 15 days, at $3		$45.00
1 carpenter, 2 days, a $3		6.00
1 cleaner, 157 days, at $1		157.00
1 agent, 6 months, at $91.66⅔		550.00
1 agent, 6 months, at $50		300.00
1 agent, 6 months, at $15		90.00
Total salaries or compensation		16,299.98
General expenses:		
Boxes	$704.25	
Books	6.75	
Freight	4,703.83	
Furniture	31.00	
Stationery	223.21	
Supplies	57.97	
Travel	17.00	
	5,744.01	
Total disbursements		$22,043.99
Balance July 1, 1902		1,956.01

INTERNATIONAL EXCHANGES, SMITHSONIAN INSTITUTION, 1901.

Balance July 1, 1901, as per last report	$2,935.71

DISBURSEMENTS.

General expenses:		
Books	$51.00	
Boxes	476.75	
Freight	1,601.42	
Furniture	245.75	
Postage	187.71	
Stationery	270.78	
Supplies	78.75	
Total disbursements		2,912.16
Balance July 1, 1902		23.55

INTERNATIONAL EXCHANGES, SMITHSONIAN INSTITUTION, 1900.

Balance July 1, 1901, as per last report	$53.90

Balance carried, under provisions of Revised Statutes, section 3080, by the Treasury Department to the credit of the surplus fund, June 30, 1902.

AMERICAN ETHNOLOGY, SMITHSONIAN INSTITUTION, 1902.

RECEIPTS.

Appropriation by Congress for the fiscal year ending June 30, 1902, "for continuing ethnological researches among the American Indians, under the direction of the Smithsonian Institution, including salaries or compensation of all necessary employees and the purchase of necessary books and periodicals, fifty thousand dollars, of which sum not exceeding one thousand five hundred dollars may be used for rent of building" (sundry civil act, March 3, 1901)	$50,000.00

The actual conduct of these investigations has been continued by the Secretary in the hands of Maj. J. W. Powell, director of the Bureau of American Ethnology.

DISBURSEMENTS.

Salaries or compensation:		
1 director, 12 months, at $375		$4,500.00
1 ethnologist, in charge, 12 months, at $333.33		3,999.96
1 ethnologist, 12 months, at $200		2,400.00
1 ethnologist, 12 months, at $166.67		2,000.04
1 ethnologist, 12 months, at $166.67		2,000.04
1 ethnologist, 12 months, at $133.33		1,599.96
1 ethnologist, 2½ months, at $125		312.50
1 ethnologist, 12 months, at $125		1,500.00
1 ethnologist, 12 months, at $125		1,500.00
1 assistant ethnologist {6 months, at $125; 6 months, at $100}		1,350.00
1 assistant ethnologist, 12 months, at $75		900.00
1 illustrator, 12 months, at $166.67		2,000.04
1 clerk, 3 months, at $125		375.00
1 clerk, 7 months, at $100		700.00
1 clerk, 12 months, at $100		1,200.00
1 clerk, 12 months, at $100		1,200.00
1 clerk, 4½ months, at $83.33		374.98
1 clerk, 12 months, at $75		900.00
1 editor, 4 months, at $100		400.00
1 librarian, 12 months, at $75		900.00
1 skilled laborer, 12 months, at $60		720.00
1 laborer, 12 months, at $60		720.00
1 laborer, 12 months, at $45		540.00
1 laborer, 225 days, at $1.50		337.50
1 messenger, 12 months, at $50		600.00
Total salaries or compensation		33,030.02
General expenses:		
Books and binding	$1,401.78	
Drawings and illustrations	690.50	
Freight	80.43	
Furniture	25.75	
Lighting	125.86	
Manuscript	1,401.99	
Miscellaneous	111.55	
Postage, telegraph, and telephones	67.50	
Rental	1,375.00	
Special services	1,788.50	
Specimens	2,920.25	
Stationery	731.07	
Supplies	586.20	
Traveling and field expenses	2,687.42	
		13,993.80
Total disbursements		47,023.82
Balance July 1, 1902		2,976.18

AMERICAN ETHNOLOGY, 1901.

Balance July 1, 1901, as per last report	$2,684.69

DISBURSEMENTS.

General expenses:		
Books and binding	$201.05	
Drawings and illustrations	104.31	
Electricity	33.93	
Freight	160.19	
Manuscript	330.00	
Miscellaneous	16.89	
Postage and telegraph	15.62	
Services	27.00	
Special services	34.00	
Specimens	1,057.90	
Supplies	257.83	
Traveling and field expenses	444.04	
Total disbursements		$2,682.76
Balance July 1, 1902		1.93

AMERICAN ETHNOLOGY, 1900.

Balance July 1, 1901, as per last report	$5.19

Balance carried, under provisions of Revised Statutes, section 3090, by the Treasury Department to the credit of the surplus fund, June 30, 1902.

NATIONAL MUSEUM—PRESERVATION OF COLLECTIONS, 1902.

RECEIPTS.

Appropriation by Congress for the fiscal year ending June 30, 1902, "for continuing the preservation, exhibition, and increase of the collections from the surveying and exploring expeditions of the Government, and from other sources, including salaries or compensation of all necessary employees, $180,000, of which sum $5,500 may be used for necessary drawings and illustrations for publications of the National Museum, and all other necessary incidental expenses" (Sundry civil act, March 3, 1901)	$180,000.00

EXPENDITURES.

[July 1, 1901, to June 30, 1902.]

Salaries or compensation	$161,882.99		
Special services	1,815.55		
Total services		$163,698.54	
Miscellaneous:			
Drawings and illustrations	$2,147.05		
Supplies	3,505.39		
Stationery	1,753.18		
Travel	1,919.22		
Freight	1,266.84		
Total miscellaneous		10,591.68	
Total expenditures			174,290.22
Balance July 1, 1902, to meet outstanding liabilities			5,709.78

Analysis of expenditures for salaries or compensation.

[July 1, 1901, to June 30, 1902.]

Scientific staff:		
1 assistant secretary, 12 months, at $258.33	$3,099.96	
1 head curator, 12 months, at $291.66	3,499.92	
1 head curator, 12 months, at $291.66	3,499.92	
1 head curator, 12 months, at $291.66	3,499.92	
1 curator, 12 months, at $200	2,400.00	
1 curator, 12 months, at $200	2,400.00	
1 curator, 12 months, at $200	2,400.00	
1 curator, 12 months, at $200	2,400.00	
1 curator, 9 months 22 days, at $175	1,703.33	
1 assistant curator, 12 months, at $150	1,800.00	
1 assistant curator, 12 months, at $150	1,800.00	
1 assistant curator, 12 months, at $150	1,800.00	
1 assistant curator, 12 months, at $150	1,800.00	
1 assistant curator, 12 months, at $150	1,800.00	
1 assistant curator, 12 months, at $133.33	1,599.96	
1 assistant curator, 12 months, at $133.33	1,599.96	
1 assistant curator, 12 months, at $125	1,500.00	
1 assistant curator, 12 months, at $116.66	1,399.92	
1 assistant curator, 12 months, at $116.66	1,399.92	
1 assistant curator, 12 months, at $116.66	1,399.92	
1 second assistant curator, 9 months 18 days, at $100	958.06	
1 aid, 12 months, at $100	1,200.00	
1 aid, 12 months, at $100	1,200.00	
1 aid, 2 months 9 days, at $100	230.00	
1 aid, 11 days, at $100	36.67	
1 aid, 12 months, at $83.33	999.96	
1 aid, 12 months, at $83.33	999.96	
1 aid, 12 months, at $83.33	999.96	
1 aid, 5 months, at $83.33; 7 months, at $75	941.65	
1 aid, 12 months, at $75	900.00	
1 aid, 3 months, at $60	180.00	
1 aid, 2 months 24 days, at $60	168.00	
1 aid, 5 months 16 days, at $60; 4 months 15 days, at $50	555.16	
1 aid, 1 month 15 days, at $60	89.03	
1 aid, 12 months, at $50	600.00	
		$52,861.18
Preparators:		
1 photographer, 12 months, at $175	2,100.00	
1 modeler, 10 months 27 days, at $100	1,087.96	
1 modeler, 59 days, at $3	177.00	
1 osteologist, 12 months, at $90	1,080.00	
1 artist, 1 month 14 days, at $125	187.50	
1 preparator, 14 days, at $100	46.67	
1 preparator, 11 months 27 days, at $90	1,071.00	
1 preparator, 12 months, at $85	1,020.00	
1 preparator, 12 months, at $85	1,020.00	
1 preparator, 12 months, at $80	960.00	
1 preparator, 12 months, at $75	900.00	
1 preparator, 12 months, at $70	840.00	
1 preparator, 12 months, at $45	540.00	
1 preparator, 1 month 12 days, at $40	55.48	

Preparators—Continued.		
1 preparator, 1 month, at $40	$40.00	
1 acting chief taxidermist, 12 months, at $125	1,500.00	
1 taxidermist, 12 months, at $100	1,200.00	
1 taxidermist, 2 months 9 days, at $90	207.00	
1 taxidermist, 3 months 2 days, at $75	229.84	
1 taxidermist, 11 months 19 days, at $60	698.00	
		$14,960.45
Clerical staff:		
1 administrative assistant, 4 months 14 days, at $291.66	1,312.47	
1 chief clerk, 3 months, at $208.34; 5 months 19 days, at $208.33	1,794.36	
1 acting chief clerk, 8 months, at $125	1,000.00	
1 editor, 12 months, at $167	2,004.00	
1 chief of division, 12 months, at $200	2,400.00	
1 registrar, 12 months, at $167	2,004.00	
1 disbursing clerk, 12 months, at $116.67	1,400.04	
1 assistant librarian, 12 months, at $133.33	1,599.96	
1 finance clerk, 12 months, at $125	1,500.00	
1 stenographer, 6 months, at $175; 6 months, at $166.66	2,049.96	
1 stenographer, 12 months, at $90	1,080.00	
1 stenographer and typewriter, 4 months, at $125	500.00	
1 stenographer and typewriter, 6 months, at $100; 6 months, at $85	1,110.00	
1 stenographer and typewriter, 8 months, at $83.33; 4 months, at $75	966.64	
1 stenographer and typewriter, 12 months, at $50	600.00	
1 stenographer and typewriter, 8 months 36 days, at $50	458.65	
1 stenographer and typewriter, 7 months 6 days, at $50	360.00	
1 stenographer and typewriter, 3 months 2 days, at $50	153.23	
1 stenographer and typewriter, 26 days, at $50	41.94	
1 typewriter, 12 months, at $85	1,020.00	
1 typewriter, 12 months, at $70	840.00	
1 typewriter, 12 months, at $65	780.00	
1 typewriter, 6 months 21 days, at $45	300.48	
1 typewriter, 4 months 19 days, at $45	208.50	
1 clerk, 12 months, at $125	1,500.00	
1 clerk, 6 months, at $125	750.00	
1 clerk, 12 months, at $115	1,380.00	
1 clerk, 12 months, at $100	1,200.00	
1 clerk, 12 months, at $100	1,200.00	
1 clerk, 12 months, at $100	1,200.00	
1 clerk, 9 months, at $100	900.00	
1 clerk, 8 months, at $100; 4 months, at $80	1,120.00	
1 clerk, 3 months, at $83.33	249.99	
1 clerk, 12 months, at $75	900.00	
1 clerk, 12 months, at $75	900.00	
1 clerk, 12 months, at $75	900.00	
1 clerk, 12 months, at $75	900.00	
1 clerk, 12 months, at $75	900.00	
1 clerk, 3 months, at $75	225.00	
1 clerk, 3 months 15 days, at $55	226.45	
1 clerk, 12 months, at $60	720.00	
1 clerk, 12 months, at $60	720.00	

Clerical staff—Continued.		
1 clerk, 12 months, at $60	$720.00	
1 clerk, 12 months, at $60	720.00	
1 clerk, 12 months, at $60	720.00	
1 clerk, 12 months, at $60	720.00	
1 clerk, 1 month, at $60	60.00	
1 clerk, 12 months, at $55	660.00	
1 clerk, 9 months, at $55	495.00	
1 clerk, 2 months 29 days, at $55; 1 month 82½ days, at $50	346.05	
1 clerk, 12 months, at $50	600.00	
1 clerk, 12 months, at $50	600.00	
1 clerk, 8 months, at $50	400.00	
1 clerk, 7 months 16 days, at $50	375.81	
1 clerk, 12 months, at $40	480.00	
1 clerk, 12 months, at $40	480.00	
1 clerk, 10 months 18 days, at $40	423.23	
1 clerk, 2 months, at $40	80.00	
1 clerk, 18½ days, at $40	23.87	
1 clerk, 12 months, at $35	420.00	
		$49,699.63
Buildings and labor:		
1 superintendent, 4 months, at $250	1,000.00	
1 general foreman, 12 months, at $122.50	1,470.00	
1 foreman, 12 months, at $50	600.00	
1 lieutenant of watch, 12 months, at $70	840.00	
1 watchman, 12 months, at $65	780.00	
1 watchman, 12 months, at $60	720.00	
1 watchman, 12 months, at $60	720.00	
1 watchman, 12 months, at $60	720.00	
1 watchman, 12 months, at $60	720.00	
1 watchman, 12 months, at $60	720.00	
1 watchman, 12 months, at $60	720.00	
1 watchman, 12 months, at $60	720.00	
1 watchman, 12 months, at $60	720.00	
1 watchman, 12 months, at $60	720.00	
1 watchman, 12 months, at $60	720.00	
1 watchman, 11 months 6 days, at $60	672.00	
1 watchman, 12 months, at $55	660.00	
1 watchman, 12 months, at $55	660.00	
1 watchman, 12 months, at $55	660.00	
1 watchman, 12 months, at $55	660.00	
1 watchman, 12 months, at $55	660.00	
1 watchman, 12 months, at $55	660.00	
1 watchman, 12 months, at $55	660.00	
1 watchman, 12 months, at $55	660.00	
1 watchman, 12 months, at $55	660.00	
1 watchman, 10 months 35 days, at $55	613.39	
1 watchman, 10 months 5 days, at $55	558.87	
1 watchman, 10 months, at $55	550.00	
1 watchman, 5 months 17 days, at $55	305.16	
1 watchman, 4 months 5 days, at $55	229.82	
1 watchman, 2 months 8 days, at $55	124.67	
1 watchman, 1 month 12 days, at $55	76.29	
1 watchman, 12 months, at $40	480.00	

Buildings and labor—Continued.

1 skilled laborer, 12 months, at $55	$660.00
1 skilled laborer, 12 months, at $50	600.00
1 skilled laborer, 12 months, at $40	480.00
1 skilled laborer, 1 month 16 days, at $40	60.65
1 workman, 313 days, at $1.50	469.50
1 laborer, 5 months, at $60; 7 months, at $50	650.00
1 laborer, 12 months, at $50	600.00
1 laborer, 12 months, at $50	600.00
1 laborer, 12 months, at $45	540.00
1 laborer, 6 months, at $45; 158 days, at $1.50	507.00
1 laborer, 14 days, at $45	20.32
1 laborer, 12 months, at $40	480.00
1 laborer, 12 months, at $40	480.00
1 laborer, 12 months, at $40	480.00
1 laborer, 12 months, at $40	480.00
1 laborer, 11 months 28 days, at $40	477.33
1 laborer, 3 months, at $40; 171 days, at $1.50	379.50
1 laborer, 2 months 29½ days, at $40	119.33
1 laborer, 2 months 19 days, at $40	104.52
1 laborer, 24 days, at $40	32.00
1 laborer, 21 days, at $40	28.00
1 laborer, 15 days, at $40	19.35
1 laborer, 12 months, at $35	420.00
1 laborer, 2 months 46 days, at $35	122.67
1 laborer, 3 months 30 days, at $30	120.48
1 laborer, 2 months 30 days, at $33.33	98.92
1 laborer, 10 months 3 days, at $25	252.42
1 laborer, 5 months 101 days, at $25	208.26
1 laborer, 2 months 6 days, at $25	55.00
1 laborer, 1 month, at $25	25.00
1 laborer, 8 months 4 days, at $20	162.58
1 laborer, 27 months 2 days, at $20	58.00
1 laborer, 2 months 6 days, at $20	44.00
1 laborer, 26 days, at $2	52.00
1 laborer, 34 days, at $1.75	59.50
1 laborer, 360 days, at $1.50	540.00
1 laborer, 325 days, at $1.50	487.50
1 laborer, 318½ days, at $1.50	477.76
1 laborer, 318½ days, at $1.50	477.75
1 laborer, 317 days, at $1.50	475.50
1 laborer, 315 days, at $1.50	472.50
1 laborer, 315 days, at $1.50	472.50
1 laborer, 314½ days, at $1.50	471.75
1 laborer, 313 days, at $1.50	469.50
1 laborer, 313 days, at $1.50	469.50
1 laborer, 313 days, at $1.50	469.50
1 laborer, 313 days, at $1.50	469.50
1 laborer, 311 days, at $1.50	466.50
1 laborer, 311 days, at $1.50	466.50
1 laborer, 310 days, at $1.50	465.00
1 laborer, 309¼ days, at $1.50	463.88
1 laborer, 155 days, at $1.50	232.50
1 laborer, 137 days, at $1.50	205.50

Buildings and labor—Continued.		
1 laborer, 105 days, at $1.50	$157.50	
1 laborer, 62 days, at $1.50	93.00	
1 laborer, 52 days, at $1.50	78.00	
1 laborer, 40 days, at $1.50	60.00	
1 laborer, 46 days, at $1.50	69.00	
1 laborer, 46 days, at $1.50	69.00	
1 laborer, 27 days, at $1.50	40.50	
1 laborer, 29 days, at $1.50	43.50	
1 laborer, 18 days, at $1.50	27.00	
1 laborer, 17 days, at $1.50	25.50	
1 laborer, 17 days, at $1.50	25.50	
1 laborer, 15 days, at $1.50	22.50	
1 laborer, 12 days, at $1.50	18.00	
1 laborer, 10 days, at $1.50	15.00	
1 laborer, 7 days, at $1.50	10.50	
1 laborer, 6½ days, at $1.50	9.75	
1 laborer, 6½ days, at $1.50	9.75	
1 laborer, 5 days, at $1.50	7.50	
1 messenger, 1 month 28 days, at $35	66.61	
1 messenger, 12 months, at $20	240.00	
1 attendant, 12 months, at $40	480.00	
1 attendant, 322½ days, at $1.50	483.75	
1 attendant, 155 days, at $1	155.00	
1 attendant, 22 days, at $1	22.00	
1 attendant, 34 days, at $1	34.00	
1 attendant, 5 days, at $1	5.00	
1 attendant, 4 days, at $1	4.00	
1 cleaner, 1 month, at $39.50; 10 months 28 days, at $35	422.17	
1 cleaner, 12 months, at $35	420.00	
1 cleaner, 12 months, at $35	420.00	
1 cleaner, 1 month, at $33; 9 months, at $30; 52 days, at $1.50	381.00	
1 cleaner, 12 months, at $30	360.00	
1 cleaner, 12 months, at $30	360.00	
1 cleaner, 11 months 19 days, at $30	348.39	
1 cleaner, 11 months 15 days, at $30	344.52	
1 cleaner, 4 months 23 days, at $30	144.64	
1 cleaner, 4 months 4 days, at $30	124.00	
1 cleaner, 1 month 16 days, at $30	45.48	
		$44,361.73
Total salaries		161,882.99

PRESERVATION OF COLLECTIONS, 1901.

RECEIPTS.

Balance as per report July 1, 1901	$6,507.92

EXPENDITURES.

[July 1, 1901, to June 30, 1902.]

Salaries or compensation	$328.00	
Special services	1,164.38	
Total services		$1,492.38

Miscellaneous:			
Drawings and illustrations	$425.77		
Supplies	1,469.71		
Stationery	460.62		
Travel	1,771.21		
Freight	813.74		
Total miscellaneus		$4,941.05	
Total expenditure			$6,433.43
Balance July 1, 1902			74.49

Analysis of expenditures for salaries or compensation.

[July 1, 1901, to June 30, 1902.]

1 collector, 2 months, at $100	$200.00	
1 collector, 1 month	125.00	
1 captain of the watch, 1 day, at $3	3.00	
Total expenditure		$328.00

Total statement of receipts and expenditures.

[July 1, 1900, to June 30, 1902.]

RECEIPTS.

Appropriation by Congress, June 6, 1900	$180,000.00

EXPENDITURES.

Salaries or compensation	$159,174.45		
Special services	5,190.14		
Total services		$164,364.59	
Miscellaneous:			
Drawings and illustrations	2,436.30		
Supplies	6,086.85		
Stationery	1,751.99		
Travel	3,490.19		
Freight	1,795.59		
Total miscellaneous		15,560.92	
Total expenditure			179,925.51
Balance July 1, 1902			74.49

PRESERVATION OF COLLECTIONS, 1900.

RECEIPTS.

Balance as per report July 1, 1901	$331.39

EXPENDITURES.

[July 1, 1901, to June 30, 1902.]

Supplies	$108.05
Freight and cartage	14.03

Drawings and illustrations	$30.00	
Special services	139.16	
Total expenditure		$291.24
Balance		40.15

Balance carried, under provisions of Revised Statutes, section 3090, by the Treasury Department to the credit of the surplus fund, June 30, 1902.

Total statement of receipts and expenditures.

[July 1, 1899, to June 30, 1902.]

RECEIPTS.

Appropriation by Congress March 3, 1899	$170,000.00

EXPENDITURES.

Salaries or compensation	$145,476.10	
Special services	1,890.48	
Total services		$147,366.58
Miscellaneous:		
Drawing and illustrations	934.99	
Supplies	4,394.52	
Stationery	1,809.82	
Specimens	10,569.52	
Travel	2,360.06	
Freight	2,533.36	
Total miscellaneous		22,593.27
Total expenditures		169,959.85
Balance		40.15

Balance carried, under provisions of Revised Statutes, section 3090, by the Treasury Department to the credit of the surplus fund, June 30, 1902.

NATIONAL MUSEUM—FURNITURE AND FIXTURES, 1902.

RECEIPTS

Appropriation by Congress for the fiscal year ending June 30, 1902, "for cases, furniture, fixtures, and appliances required for the exhibition and safe keeping of the collections of the National Museum, including salaries or compensation of all necessary employees" (sundry civil act, March 3, 1901)	$20,000.00

EXPENDITURES.

[July 1, 1901, to June 30, 1902.]

Salaries or compensation	$11,742.49	
Special services	24.40	
Total services		$11,766.89

Miscellaneous:		
Storage cases	$230.00	
Drawers, trays, etc	525.25	
Frames and woodwork	314.95	
Glass	1,193.21	
Hardware	811.64	
Tools	37.61	
Cloth	72.04	
Lumber	1,320.52	
Paints, oils, etc	299.68	
Office furniture	641.55	
Leather, rubber, cork	305.66	
Drawings	103.00	
Plumbing	189.55	
Paper	51.00	
Flour	1.30	
Total miscellaneous		$6,096.96
Total expenditures		$17,863.85
Balance July 1, 1902, to meet outstanding liabilities		2,136.15

Analysis of expenditures for salaries or compensation.

[July 1, 1901, to June 30, 1902.]

1 supervisor of construction, 12 months, at $127.50	$1,530.00
1 shop foreman, 313 days, at $3.25	1,017.25
1 carpenter, 314 days, at $3	942.00
1 carpenter, 313 days, at $3	939.00
1 carpenter, 260 days, at $3	780.00
1 carpenter, 209 days, at $3	627.00
1 carpenter, 208 days, at $3	624.00
1 carpenter, 158 days, at $3	474.00
1 carpenter, 76 days, at $3	228.00
1 carpenter, 73 days, at $3	219.00
1 carpenter, 38¼ days, at $3	114.75
1 carpenter, 8 days, at $3	24.00
1 carpenter, 1 day, at $3	3.00
1 skilled laborer, 280½ days, at $2	561.00
1 skilled laborer, 6 months 70½ days, at $65	540.73
1 skilled laborer, 6 months, at $83.33	499.98
1 skilled laborer, 3 months, at $60	180.00
1 skilled laborer, 53 days, at $2	106.00
1 skilled laborer, 52 days, at $2	104.00
1 skilled laborer, 10 days, at $3.50	35.00
1 painter, 11 months 4 days, at $75	835.00
1 workman, 323⅞ days, at $1.75	566.78
1 clerk, 2 months, at $70	140.00
1 laborer, 232 days, at $1.75	406.00
1 laborer, 113 days, at $1.50	169.50
1 laborer, 51 days, at $1.50	76.50
Total salaries or compensation	11,742.49

FURNITURE AND FIXTURES, 1901.

RECEIPTS.

Balance as per report July 1, 1901	$2,096.23

EXPENDITURES.

[July 1, 1901, to June 30, 1902.]

Salaries or compensation	$12.00		
Total services		$12.00	
Miscellaneous:			
Drawers, trays, etc	26.25		
Frames and woodwork	20.00		
Glass	52.30		
Hardware	168.49		
Tools	41.27		
Cloth	88.02		
Lumber	182.17		
Paints, oils, etc	123.71		
Office furniture	181.77		
Leather and rubber	2.98		
Drawings	120.00		
Plumbing	496.43		
Flour	1.20		
Total miscellaneous		1,504.59	
Total regular expenditure			$1,516.59
Lecture hall:			
Frames and framework		138.70	
Hardware		20	
Cloth		16.50	
Lumber		43.35	
Chairs		312.00	
Miscellaneous furnishings		67.00	
Total lecture hall			577.75
Total expenditure			2,094.34
Balance July 1, 1902			1.89

Total statement of receipts and expenditures.

[July 1, 1900, to June 30, 1902.]

RECEIPTS.

Appropriation by Congress June 6, 1900	$17,500.00

EXPENDITURES.

[July 1, 1900, to June 30, 1902.]

Salaries or compensation	$8,095.78	
Special services	11.50	
Total services		$8,107.28

Miscellaneous:			
Exhibition cases	$95.00		
Storage cases	587.00		
Drawers, trays, etc	194.00		
Frames and woodwork	331.65		
Glass	397.73		
Hardware	556.91		
Tools	147.44		
Cloth, etc	186.47		
Glass jars	60.06		
Lumber	1,129.36		
Paints, oils, etc	374.41		
Office furniture	934.18		
Leather, rubber, and cork	212.64		
Drawings for cases	161.75		
Plumbing	1,494.95		
Flour	1.20		
Paper	26.16		
Total miscellaneous		$6,890.91	
Total expenditure		14,998.19	
Lecture hall:			
Salaries or compensation	547.50		
Frames and woodwork	363.92		
Hardware	17.37		
Cloth, etc	63.63		
Lumber	125.74		
Chairs	792.00		
Mortar and plaster	3.25		
Miscellaneous furnishings	67.00		
Stereopticon, etc	331.00		
Paints, oils, etc	138.51		
Drawings for cases	50.00		
Total expenditure for lecture hall		2,499.92	
Total expenditure of appropriation			$17,498.11
Balance July 1, 1902			1.89

FURNITURE AND FIXTURES, 1900.

RECEIPTS.

Balance as per report July 1, 1901	$11.85

Balance carried, under provisions of Revised Statutes, section 3090, by the Treasury Department to the credit of the surplus fund June 30, 1902.

NATIONAL MUSEUM—HEATING AND LIGHTING, 1902.

RECEIPTS.

Appropriation by Congress for the fiscal year ending June 30, 1902, "for expense of heating, lighting, electrical, telegraphic, and telephonic service for the National Museum, including $5,000 for electrical installation" (sundry civil act, March 3, 1901)	$23,000.00

EXPENDITURES, REGULAR.

[July 1, 1901, to June 30, 1902.]

Salaries or compensation	$8,419.13	
Special services	27.75	
Total services		$8,446.88
Miscellaneous:		
Coal and wood	$4,486.52	
Gas	1,278.70	
Rental of call boxes	100.00	
Electrical supplies	317.86	
Electricity	782.80	
Heating supplies	574.08	
Telegrams	2.29	
Telephones	484.94	
Total miscellaneous, regular		8,027.19
Total regular expenditure		$16,474.07

ELECTRIC INSTALLATION.

RECEIPTS.

Appropriation, "* * * including $5,000 for electric installation."

EXPENDITURES.

[July 1, 1901, to June 30, 1902.]

Salaries or compensation	$2,090.48	
Miscellaneous:		
Supplies	$2,721.95	
Tools	4.18	
Woodwork	148.89	
Total miscellaneous installation	2,875.02	
Total electric installation		4,965.50
Total disbursements		21,439.57
Balance July 1, 1902		1,560.43

Analysis of expenditures for salaries or compensation.

[July 1, 1901, to June 30, 1902.]

1 engineer, 12 months, at $122.50	$1,470.00
1 telephone operator, 6 months, at $40; 6 months, at $45	510.00
1 telephone operator, 30 days, at $150	45.00
1 superintendent, 4 months, at $250	1,000.00
1 clerk, 2 months, at $60	120.00
1 fireman, 12 months, at $60	720.00
1 fireman, 12 months, at $55	660.00
1 skilled laborer, 259¾ days, at $3	779.25
1 skilled laborer, 6 months, at $75	450.00
1 skilled laborer, 44 days, at $3.50	154.00

1 skilled laborer, 76 days, at $3.50	$266.00
1 skilled laborer, 33 days, at $3.50	115.50
1 skilled laborer, 30 days, at $3.50	105.00
1 skilled laborer, 26 days, at $3.50; 1 day, at $3	94.00
1 skilled laborer, 21 days, at $3.50	73.50
1 skilled laborer, 9 days, at $3.50	31.50
1 skilled laborer, 8½ days, at $3.50	29.75
1 skilled laborer, 6 days, at $3.50	21.00
1 skilled laborer, 5 days, at $3.50	17.50
1 laborer, 244½ days, at $2	488.50
1 laborer, 278¾ days, at $1.50	418.13
1 laborer, 265 days, at $1.50	397.50
1 laborer, 259 days, at $1.50	388.50
1 laborer, 25 days, at $1.50	37.50
1 laborer, 18 days, at $1.50	27.00
Total salaries or compensation	8,419.13

ELECTRICAL INSTALLATION, 1902.

1 acting electric foreman, 6 months, at $83.33	499.98
1 clerk, 1 month, at $70	70.00
1 skilled laborer, 5 months 26½ days, at $75	441.25
1 skilled laborer, 139 days, at $3	417.00
1 skilled laborer, 18½ days, at $3	55.50
1 laborer, 199 days, at $1.50	298.50
1 laborer, 193½ days, at $1.50	290.25
1 laborer, 3 days, at $1.50	4.50
1 laborer, 3 days, at $1.50	4.50
1 laborer, 3 days, at $1.50	4.50
1 laborer, 3 days, at $1.50	4.50
Total electrical installation	2,090.48

HEATING AND LIGHTING, 1901.

RECEIPTS.

Balance as per report July 1, 1901	$1,888.09

EXPENDITURES.

[July 1, 1901, to June 30, 1902.]

Special services	$33.70	
Total services		$33.70
Miscellaneous:		
Coal and wood	$99.57	
Gas	92.50	
Electricity	169.06	
Telephones	138.54	
Electrical supplies	489.19	
Rent of call boxes	20.00	
Heating supplies	266.11	
Telegrams	11.08	
Total miscellaneous		1,286.05
Total regular appropriation		$1,319.75

Electric installation:			
Supplies	$562.11		
Woodwork	6.00		
Total electric installation		$568.11	
Total expenditures			$1,887.86
Balance July 1, 1902			.23

Total statement of receipts and expenditures.

[July 1, 1900, to June 30, 1902.]

RECEIPTS.

Appropriation by Congress June 6, 1900	$17,500.00

EXPENDITURES, REGULAR.

[July 1, 1900, to June 30, 1902.]

Salaries or compensation	$6,097.07		
Special services	98.30		
Total services, regular		$6,195.37	
Miscellaneous:			
Coal and wood	3,631.42		
Gas	1,224.40		
Rental of call boxes	120.00		
Electrical supplies	800.63		
Electricity	646.77		
Heating supplies	767.82		
Telegrams	40.25		
Telephones	573.19		
Total miscellaneous, regular		7,804.48	
Total regular expenditure			$13,999.85

ELECTRIC INSTALLATION.

RECEIPTS.

Included in appropriation of $17,500	$3,500.00

EXPENDITURES.

Salaries or compensation	$858.40		
Special services	3.00		
Total services		$861.40	
Miscellaneous:			
Drawings	$55.50		
Supplies	2,193.47		
Tools	20.14		
Woodwork	334.30		
Travel	35.11		
Total miscellaneous, electric installation		2,638.52	
Total electric installation			3,499.92
Total expenditure			$17,499.77
Balance July 1, 1902			.23

HEATING AND LIGHTING, 1900.

RECEIPTS.

Balance as per report July 1, 1901	$0.02

Balance carried, under provisions of Revised Statutes, section 3090, by the Treasury Department to the credit of the surplus fund, June 30, 1902.

NATIONAL MUSEUM—POSTAGE, 1902.

RECEIPTS.

Appropriation by Congress for the fiscal year ending June 30, 1902, "for postage stamps and foreign postal cards for the National Museum" (sundry civil act, March 3, 1901)	$500.00

EXPENDITURES.

[July 1, 1901, to June 30, 1902.]

Postage stamps and foreign postal cards	500.00

NATIONAL MUSEUM—PRINTING AND BINDING, 1902.

RECEIPTS.

Appropriation by Congress for ths fiscal year ending June 30, 1902, "for the Smithsonian Institution, for printing labels and blanks and for the Bulletins and Proceedings of the National Museum, the editions of which shall not be less than 3,000 copies, and binding in half turkey, or material not more expensive, scientific books and pamphlets presented to and acquired by the National Museum Library" (sundry civil act, March 3, 1901)	$17,000.00

EXPENDITURES.

[July 1, 1901, to June 30, 1902.]

Bulletins of the Museum	$7,060.41	
Proceedings of the Museum	7,284.27	
Labels	646.95	
Blanks	231.10	
Congressional Record	32.00	
Congressional documents	165.50	
Record books	86.30	
Binding	1,361.60	
Total expenditures		16,868.13
Balance July 1, 1902		131.87

NATIONAL MUSEUM—RENT OF WORKSHOPS, 1902.

RECEIPTS.

Appropriation by Congress for the fiscal year ending June 30, 1902, "for rent of workshops and temporary storage quarters for the National Museum" (sundry civil act, March 3, 1901)	$4,400.00

EXPENDITURES.

[July 1, 1901, to June 30, 1902.]

Total expenditures	4,399.92
Balance July 1, 1902	08

RENT OF WORKSHOPS

Balance July 1, 1901	$0.08
Balance July 1, 1902	08

RENT OF WORKSHOPS, 1900.

Balance as per report July 1, 1901	$0.08

Balance carried, under provisions of Revised Statutes, section 3090, by the Treasury Department to the credit of the surplus fund, June 30, 1902.

NATIONAL MUSEUM—BUILDING REPAIRS, 1902.

RECEIPTS.

Appropriation by Congress for the fiscal year ending June 30, 1902 (sundry civil act, March 3, 1901):	
"For repairs to buildings, shops, and sheds, National Museum, including all necessary labor and material"	$15,000.00
"For removing old boilers in the National Museum building, and for the purchase and installation of new boilers, including material and labor for necessary alterations and connections"	12,500.00
Total	27,500.00

EXPENDITURES.

[July 1, 1901, to June 30, 1902.]

Salaries or compensation	$9,512.29	
Special services	649.35	
Total services		$10,161.64
Miscellaneous:		
Lumber	532.51	
Cement, plaster, gravel, lime, sand	339.05	
Hardware, tools, etc	697.32	
Paints, oils, brushes, etc	421.47	
Woodwork	164.30	
Skylights and ventilators	566.40	
Glass	56.27	
Marble mosaic floor and tiles	192.72	
Sewer connections	200.00	
Drawings	85.00	
Cloth, cotton	6.19	
Paper	57.85	
Total miscellaneous		3,319.08
Total expenditure, regular appropriation		$13,480.72

New boilers.

Salaries or compensation	$2,801.93	
Special services	31.61	
Total services		$2,833.54
Miscellaneous:		
Advertising	35.63	
Drawings	12.75	

Miscellaneous—Continued.			
Concrete foundations and brickwork (by contract)	$915.00		
Brick, stone, cement, lime, gravel, sand	628.00		
Pipe and fittings	863.20		
Pipe covering	131.36		
Hardware and tools	365.19		
Lumber	12.06		
Asphalt pavement	117.75		
Two water-tube boilers, complete	6,000.00		
Removing dirt	127.50		
Lard oil, etc	6.50		
Traveling expenses	32.50		
Total miscellaneous		$9,247.44	
Total expenditure, new boilers			$12,080.98
Total disbursements			$25,561.70
Balance July 1, 1902			1,938.30

Analysis of expenditures for salaries or compensation.

[July 1, 1901, to June 30, 1902.]

1 superintendent, 4 months, at $250	$1,000.00
1 foreman, 289⅜ days, at $3.25	940.47
1 clerk, 1 month 23 days, at $70	123.67
1 stenographer and typewriter, 2 months, at $40	80.00
1 carpenter, 292 days, at $3	876.00
1 carpenter, 279¼ days, at $3	837.75
1 carpenter, 111 days, at $3	333.00
1 carpenter, 104¼ days, at $3	312.75
1 carpenter, 53 days, at $3	159.00
1 carpenter, 46¼ days, at $3	138.75
1 carpenter, 39 days, at $3	117.00
1 carpenter, 25 days, at $3	75.00
1 carpenter, 19 days, at $3	57.00
1 carpenter, 11 days, at $3	33.00
1 carpenter, 5 days, at $3	15.00
1 skilled laborer, 199 days, at $2	398.00
1 skilled laborer, 198½ days, at $2	397.00
1 skilled laborer, 4 months, at $70	280.00
1 skilled laborer, 156½ days, at $2	313.00
1 skilled laborer, 141 days, at $2	282.00
1 skilled laborer, 2 months 20 days, at $65 per month	190.81
1 skilled laborer, 3 months, at $60	180.00
1 skilled laborer, 40½ days, at $2.50	101.25
1 skilled laborer, 24 days, at $1.66⅔	40.00
1 skilled laborer, 10 days, at $2	20.00
1 skilled laborer, 3 days, at $2.50	7.50
1 laborer, 147¼ days, at $2	294.50
1 laborer, 66 days, at $2	132.00
1 laborer, 132 days, at $1.75	231.01
1 laborer, 130¾ days, at $1.75	228.81
1 laborer, 127½ days, at $1.75	223.13
1 laborer, 133¼ days, at $1.50	199.98

1 laborer, 105¾ days, at $1.75	$185.06
1 laborer, 102¼ days, at $1.75	178.94
1 laborer, 79 days, at $1.75	138.25
1 laborer, 75½ days, at $1.75	132.13
1 laborer, 30¾ days, at $1.50	46.13
1 laborer, 24 days, at $1.50	36.00
1 laborer, 23½ days, at $1.50	35.25
1 laborer, 23½ days, at $1.50	35.25
1 laborer, 15 days, at $1.50	22.50
1 laborer, 15 days, at $1.50	22.50
1 laborer, 15 days, at $1.50	22.50
1 laborer, 9 days, at $1.50	13.50
1 laborer, 8 days, at $1.50	12.00
1 laborer, 5 days, at $1.50	7.50
1 laborer, 6 days, at $1.25	7.50
	9,512.29

NEW BOILERS.

1 steam fitter, 26 days, at $3	$78.00
1 steam fitter 23 days, at $3	69.00
1 clerk, 1 month, at $70	70.00
1 skilled laborer, 2 months, at $70	140.00
1 skilled laborer, 54 days, at $3	162.00
1 skilled laborer, 39 days, at $2.50	97.50
1 skilled laborer, 9¼ days, at $2.50	23.13
1 carpenter, 48 days, at $3	144.00
1 carpenter, 41 days, at $3	123.00
1 helper, 40 days, at $1.50	60.00
1 helper, 44¾ days, at $1.50	67.13
1 helper, 40 days, $1.50	60.00
1 helper, 39½ days, at $1.50	59.25
1 helper, 35 days, at $1.50	52.50
1 helper, 24 days, at $1.50	36.00
1 laborer, 58 days, at $2	116.00
1 laborer, 57 days, at $2	114.00
1 laborer, 62 days, at $1.75	108.50
1 laborer, 56 days, at $1.75	98.00
1 laborer, 54 days, at $1.75	94.50
1 laborer, 54 days, at $1.75	94.50
1 laborer, 59¼ days, at $1.50	88.88
1 laborer, 55 days, at $1.50	82.50
1 laborer, 54 days, at $1.50	81.00
1 laborer, 54 days, at $1.50	81.00
1 laborer, 53 days, at $1.50	79.50
1 laborer, 51½ days, at $1.50	77.26
1 laborer, 42½ days, at $1.50	63.76
1 laborer, 41¼ days, at $1.50	61.88
1 laborer, 36½ days, at $1.50	54.75
1 laborer, 35¼ days, at $1.50	53.63
1 laborer, 34¾ days, at $1.50	52.13
1 laborer, 28 days, at $1.50	42.00
1 laborer, 27 days, at $1.50	40.50
1 laborer, 22 days, at $1.50	34.13
1 laborer, 42 days, at $1	42.00
	2,801.93

BUILDING REPAIRS, 1901.

RECEIPTS.

Balance as per report July 1, 1901	$884.93

EXPENDITURES.

[July 1, 1901, to June 30, 1902.]

Special services	$35.00	
Total services		$35.00
Miscellaneous:		
Lumber	30.28	
Cement, plaster, gravel, lime, sand	110.20	
Brick	69.33	
Hardware, tools, etc	362.30	
Paints, oils, brushes, etc	169.85	
Woodwork	5.65	
Glass	1.35	
Terazzo and tile floors	15.75	
Marble capping	25.00	
Paper	1.25	
Steel plates, angles, etc	58.93	
Total miscellaneous		849.89
Total regular		884.89
Balance July 1, 1902		.04

Total statement of receipts and expenditures.

[July 1, 1900, to June 30, 1902.]

RECEIPTS.

Appropriation by Congress June 6, 1900	$15,000.00

EXPENDITURES.

[July 1, 1900, to June 30, 1902.]

Salaries or compensation	$7,661.44	
Special services	477.85	
Total services		$8,139.29
Miscellaneous:		
Terazzo and tile floors	2,052.76	
Lumber	316.85	
Cement, gravel, sand, etc	585.80	
Hardware and tools	533.09	
Paints, oils, brushes	399.64	
Skylights and ventilator	240.00	
Steel plates, angles, panels, etc	1,181.02	
Drawings	281.50	
Advertising	41.26	
Travel	52.35	
Woodwork	248.27	
Bricks	128.83	

Miscellaneous—Continued.			
Glass	$5.15		
Decorating walls and ceilings	767.90		
Marble capping	25.00		
Paper	1.25		
Total miscellaneous		$6,860.67	
Total expenditure			$14,999.96
Balance July 1, 1902			.04

BUILDING REPAIRS, 1900.

Balance as per report July 1, 1901 $0.85

Balance carried, under provisions of Revised Statutes, section 3090, by the Treasury Department to the credit of the surplus fund, June 30, 1902.

NATIONAL MUSEUM—GALLERIES, 1902.

RECEIPTS.

Appropriation by Congress for the fiscal year ending June 30, 1902, "for construction of two galleries in the National Museum building" (sundry civil act, March 3, 1901) $5,000.00

EXPENDITURES.

[July 1, 1901, to June 30, 1902.]

Salaries or compensation	$2,404.02		
Special services	3.50		
Total services		$2,407.52	
Miscellaneous:			
Hardware, tools, etc	269.61		
Cement, gravel, sand, stone, etc	360.92		
Cloth, cotton	24.28		
Brushes	2.50		
Lumber	113.99		
Steel beams, iron posts, etc	1,440.51		
Woodwork	52.75		
Paper	15.00		
Fireproof partitions	275.00		
Total miscellaneous		2,554.56	
Total expenditures			4,962.08
Balance July 1, 1902			37.92

Analysis of expenditures for salaries or compensation.

[July 1, 1901, to June 30, 1902.]

1 foreman, 26 days, at $3.25	$84.50
1 clerk, 1 month, at $70	70.00
1 skilled laborer, 6 months, at $70	420.00
1 skilled laborer, 6 months, at $60	360.00
1 laborer, 159⅞ days, at $1.75	279.78

1 laborer, 136¼ days, at $2	$272.50
1 laborer, 139½ days, at $1.75	243.69
1 laborer, 135⅞ days, at $1.75	241.29
1 laborer, 130 days, at $1.75	227.50
1 laborer, 136½ days, at $1.50	204.76
Total salaries	2,404.02

NATIONAL MUSEUM—BOOKS, 1902.

RECEIPTS.

Appropriation by Congress for the fiscal year ending June 30, 1902, "for purchase of books, pamphlets, and periodicals for reference in the National Museum" (sundry civil act, March 3, 1901)	$2,000.00

EXPENDITURES.

[July 1, 1901, to June 30, 1902.]

Total expenditures	857.03
Balance July 1, 1902	1,142.97

BOOKS, 1901.

RECEIPTS.

Balance, as per report, July 1, 1901	$858.04

EXPENDITURES.

[July 1, 1901, to June 30, 1902.]

Total expenditures	765.90
Balance July 1, 1902	92.14

BOOKS, 1900.

RECEIPTS.

Balance, as per report, July 1, 1901	$30.64

EXPENDITURES.

[July 1, 1901, to June 30, 1902.]

For books	2.55
Balance	28.09

Balance carried, under provisions of Revised Statutes, section 3090, by the Treasury Department to the credit of the surplus fund, June 30, 1902.

NATIONAL MUSEUM—PURCHASE OF SPECIMENS.

RECEIPTS.

Appropriation by Congress for the fiscal year ending June 30, 1902, "for purchase of specimens to supply deficiencies in the collections of the National Museum" (sundry civil act, March 3, 1901)	$10,000.00

EXPENDITURES

[July 1, 1901, to June 30, 1902.]

Total expenditures	7,528.70
Balance July 1, 1902, to meet outstanding liabilities	2,471.30

PURCHASE OF SPECIMENS, 1901.

RECEIPTS.

Balance as per report July 1, 1901	$3,058.56

EXPENDITURES.

[July 1, 1901, to June 30, 1902.]

Total expenditures	2,986.39
Balance July 1, 1902	72.17

ASTROPHYSICAL OBSERVATORY, SMITHSONIAN INSTITUTION, 1902.

RECEIPTS.

Appropriation by Congress for the fiscal year ending June 30, 1902, "for maintenance of Astrophysical Observatory, under the direction of the Smithsonian Institution, including salaries of assistants, the purchase of necessary books and periodicals, apparatus, printing and publishing results of researches, not exceeding one thousand five hundred copies, repairs and alterations of buildings, and miscellaneous expenses, twelve thousand dollars; that the Secretary of the Smithsonian Institution is directed to report to Congress on the first day of the next regular session an entire account of all appropriations heretofore expended by the Astrophysical Observatory, what results have been reached, and what is the present condition of the work of said Observatory" (sundry civil act, March 3, 1901)	$12,000.00

DISBURSEMENTS.

Salaries or compensation:		
1 aid, 12 months, at $175	$2,100.00	
1 assistant, 25½ days, at $125	104.84	
1 assistant, ½ month, at $90	45.00	
1 junior assistant, 12 months, at $110	1,320.00	
1 clerk, 1 month, at $125	125.00	
1 stenographer, 11 months, at $100	1,100.00	
1 stenographer, 1 month, at $50	50.00	
1 instrument maker, 11 months and 9½ days, at $80	904.69	
1 fireman, 12 months, at $50	600.00	
1 cleaner, 158 days, at $1	158.00	
1 laborer, 4 months and 4 days, at $20	82.86	
Total salaries or compensation		$6,590.39
General expenses:		
Apparatus	855.20	
Books	120.90	
Building repairs	146.50	
Drawings	30.00	
Electricity	195.08	
Furniture	52.75	
Freight and hauling	9.19	
Lumber	4.06	
Publications	294.00	

General expenses—Continued.		
Supplies	$578.52	
Special services	869.72	
	$3,155.92	
Total disbursements		$9,746.31
Balance July 1, 1902		2,253.69

ASTROPHYSICAL OBSERVATORY, 1901.

Balance July 1, 1901, as per last report	$79.80

DISBURSEMENTS.

General expenses:		
Apparatus	$25.00	
Books	8.28	
Gas and electricity	24.22	
Supplies	21.38	
Total disbursements		78.88
Balance July 1, 1902		.92

ASTROPHYSICAL OBSERVATORY, 1900.

Balance July 1, 1901, as per last report	$2.99

Balance carried, under provisions of Revised Statutes, section 3090, by the Treasury Department to the credit of the surplus fund, June 30, 1902.

OBSERVATION OF ECLIPSE OF MAY 28, 1900.

Balance July 1, 1902, as per last report	$755.74

NATIONAL ZOOLOGICAL PARK, 1902.

RECEIPTS.

Appropriation by Congress for the fiscal year ending June 30, 1902, "for continuing the construction of roads, walks, bridges, water supply, sewerage, drainage, and for grading, planting, and otherwise improving the grounds; erecting and repairing buildings and inclosures; care, subsistence, purchase, and transportation of animals, including salaries or compensation of all necessary employees; the purchase of necessary books and periodicals; the printing and publishing of operations, not exceeding one thousand five hundred copies, and general incidental expenses not otherwise provided for, eighty thousand dollars; one-half of which sum shall be paid from the revenues of the District of Columbia and the other half from the Treasury of the United States, and of the sum hereby appropriated five thousand dollars shall be used for continuing the entrance into the Zoological Park, from Cathedral avenue and opening driveway into the Zoological Park, including necessary grading and removal of earth" (sundry civil act, March 3, 1901).	$80,000.00

DISBURSEMENTS.

Salaries or compensation:		
1 superintendent, 12 months, at $225	$2,700.00	
1 property clerk, 12 months, at $150	1,800.00	
1 clerk, 12 months, at $110	1,320.00	
1 clerk, 12 months, at $100	1,200.00	

Salaries or compensation—Continued.		
1 stenographer, 6 months, at $62.50, and 6 months, at $83.33	$874.98	
1 landscape gardener, 12 months, at $83.33	999.96	
1 photographer, 2 months, at $80	160.00	
1 photographer, 3½ months, at $70	245.00	
1 head keeper, 6 months, at $100, and 6 months, at $112.50	1,275.00	
1 keeper, 12 months, at $60	720.00	
1 keeper, 12 months, at $60	720.00	
1 keeper, 11½ months and 13 days, at $60	716.00	
1 keeper, 12 months, at $60	720.00	
1 watchman, 11½ months and 11 days, at $60	712.00	
1 watchman, 6 months, at $60, and 6 months, at $65	750.00	
1 watchman, 12 months, at $55	660.00	
1 assistant foreman, 12 months, at $65	780.00	
1 blacksmith, 6 months, at $75, and 6 months, at $83.33	949.98	
1 assistant blacksmith, 12 months, at $60	720.00	
1 workman, 12 months, at $60	720.00	
1 workman, 6 months, at $50, and 6 months, at $60	660.00	
1 laborer, 12 months, at $60	720.00	
1 laborer, 12 months, at $55	660.00	
1 laborer, 12 months, at $50	600.00	
1 laborer, 5 months and 15½ days, at $50, and 6 months, at $60	635.75	
1 laborer, 10½ months and 13 days, at $20	218.39	
Total salaries or compensation		$22,237.06
Miscellaneous:		
Buildings	$896.66	
Building material	361.74	
Fence, cage material, etc	3,406.66	
Food	11,263.08	
Freight	952.96	
Fuel	1,251.04	
Furniture	219.75	
Lumber	838.30	
Machinery, tools, etc	343.85	
Miscellaneous supplies	1,227.64	
Paints, oils, etc	149.96	
Postage and telegraph	72.24	
Purchase of animals	1,883.65	
Road material and grading	4,095.46	
Special services	62.50	
Stationery, books, etc	359.93	
Surveying, plans, etc	495.20	
Traveling and field expenses	62.78	
Trees, plants, etc	41.00	
Water supply, etc	296.46	
Total miscellaneous		28,280.86

Wages of mechanics and laborers and hire of teams in constructing buildings and inclosures, laying water pipes, building roads, gutters, and walks, planting trees, and otherwise improving the grounds:

1 tinner, 2½ days, at $4	$10.00
1 carpenter, 26 days, at $3	78.00
1 carpenter, 30 days, at $3	90.00
1 carpenter, 16 days, at $3	48.00
1 carpenter, 53 days, at $3	159.00
1 carpenter, 315¼ days, at $3	945.75
1 carpenter, 42½ days, at $3	127.50
1 carpenter, 9 days, at $3	27.00
1 painter, 10 days, at $3	30.00
1 workman, 31 days, at $1.75, and 334 days, at $2	722.25
1 laborer, 334½ days, at $2.50	836.25
1 laborer, 35 days, at $2	70.00
1 laborer, 350 days, at $2	700.00
1 laborer, 312½ days, at $2	625.00
1 laborer, 282¾ days, at $1.75	494.80
1 laborer, 337 days, at $1.75	589.75
1 laborer, 137½ days, at $1.75	240.63
1 laborer, 215¾ days, at $1.75	377.56
1 laborer, 360 days, at $1.75	630.00
1 laborer, 305¼ days, at $1.75	534.19
1 laborer, 279¼ days, at $1.75	488.69
1 laborer, 284 days, at $1.50	426.02
1 laborer, 366 days, at $1.50	549.01
1 laborer, 39 days, at $1.50	58.50
1 laborer, 103 days, at $1.50	154.50
1 laborer, 25¼ days, at $1.50	37.87
1 laborer, 9¾ days, at $1.50	14.63
1 laborer, 203¼ days, at $1.50	304.88
1 laborer, 52¾ days, at $1.50	79.12
1 laborer, 59¼ days, at $1.50	88.88
1 laborer, 81 days, at $1.50	121.50
1 laborer, 8¾ days, at $1.50	13.13
1 laborer, 118½ days, at $1.50	177.38
1 laborer, 371¼ days, at $1.50	556.89
1 laborer, 291½ days, at $1.50	437.25
1 laborer, 11½ days, at $1.50	17.25
1 laborer, 306¼ days, at $1.50	459.37
1 laborer, 365 days, at $1.50	547.50
1 laborer, 42¾ days, at $1.50	64.13
1 laborer, 275¾ days, at $1.50	413.64
1 laborer, 9½ days, at $1.50	14.25
1 laborer, 183¾ days, at $1.50	275.64
1 laborer, 10¾ days, at $1.50	16.12
1 laborer, 190¼ days, at $1.50, and 183 days, at $1.75	605.63
1 laborer, 364¾ days, at $1.50	547.13
1 laborer, 333¼ days, at $1.50	499.88
1 laborer, 106¾ days, at $1.50	160.13

Wages of mechanics, laborers, etc.—Continued.

1 laborer, 46¼ days, at $1.50	$69.38
1 laborer, 38½ days, at $1.50	57.75
1 laborer, 10 days, at $1.50	15.00
1 laborer, 212¾ days, at $1.50	319.14
1 laborer, 9 days, at $1.50	13.50
1 laborer, 42¼ days, at $1.50	63.38
1 laborer, 363 days, at $1.50	544.50
1 laborer, 39¼ days, at $1.50	58.88
1 laborer, 280¼ days, at $1.50	420.38
1 laborer, 345¾ days, at $1.50	518.62
1 laborer, 179 days, at $1.50	268.50
1 laborer, 87¼ days, at $1.50	130.88
1 laborer, 114½ days, at $1.50	171.76
1 laborer, 9 days, at $1.50	13.50
1 laborer, 344 days, at $1.50	516.03
1 laborer, 307½ days, at $1.50	461.24
1 laborer, 224 days, at $1.50	336.00
1 laborer, 73¾ days, at $1.25, and 66 days, at $1.50	191.19
1 laborer, 3 days, at $1.25, and 12¾ days, at $1.50	22.88
1 laborer, 167 days, at $1.50, and 71¼ days, at $1.25	339.55
1 laborer, 181 days, at $1.50, and 185 days, at $1.25	502.75
1 laborer, 14½ days, at $1	14.50
1 laborer, 53¼ days, at $1	53.25
1 laborer, 293 days, at $1	293.00
1 laborer, 265½ days, at $1, and 89¼ days, at $1.25	377.06
1 laborer, 97¾ days, at $1.25 and 311¾ days, at $1	433.94
1 laborer, 278¼ days, at $1	278.25
1 helper, 91 days, at $1.25, and 275¼ days, at $1	389.00
1 helper, 360½ days, at 75 cents	270.38
1 helper, 25 days, at 75 cents	18.75
1 helper, 48¾ days, at 50 cents	24.38
1 helper, 182¼ days, at 50 cents, and 129½ days, at 75 cents	188.25
1 helper, 23¾ days, at 50 cents	11.88
1 water boy, 22¼ days, at 75 cents	16.69
1 attendant, 54 days, at 75 cents	40.50
1 attendant, 8 days, at 75 cents	6.00
1 attendant, 330 days, at 75 cents	247.50
1 sand dredger, 72½ cubic yards, at 60 cents, and laborer, 60 days, at $1.50	133.50
1 stonebreaker, 35½ cubic yards, at 60 cents	21.30
1 stonebreaker, 33 cubic yards, at 60 cents	19.80
1 wagon and team, 157 days, at $3, and 91½ days, at $3.25	768.38
1 wagon and team, 17 days, at $3, and 20 days, at $3.25	116.00
1 wagon and team, 74 days, at $3	222.00

Wages of mechanics, laborers, etc.—Continued.		
1 horse and cart, 4 days, at $1.60	$6.40	
1 horse and cart, 81¾ days, at $1.50, and 16 days, at $1.60	148.23	
1 horse and cart, 94 days, at $1.50, and 55 days, at $1.60	229.00	
1 horse, 339 days, at 50 cents	169.50	
Total wages of mechanics, etc	$23,996.85	
Total disbursements		$74,514.77
Balance July 1, 1902		5,485.23

NATIONAL ZOOLOGICAL PARK, 1901.

Balance July 1, 1901, as per last report		$9,802.29

DISBURSEMENTS.

General expenses:		
Buildings	$884.42	
Building material	8.30	
Fencing, cage material, etc	2,543.41	
Food	1,056.97	
Freight	498.57	
Fuel	24.00	
Furniture	187.60	
Lumber	249.60	
Machinery, tools, etc	169.22	
Miscellaneous	230.42	
Paints, oils, glass, etc	55.76	
Postage, telegraph, and telephone	81.63	
Road material and grading	2,928.40	
Stationery, books, printing, etc	397.07	
Surveying plans, etc	414.00	
Traveling and field expenses	28.05	
Trees, plants, etc	19.30	
Water supply, sewerage, etc	8.29	
Total disbursements		9,785.01
Balance July 1, 1902		17.28

NATIONAL ZOOLOGICAL PARK, 1900.

Balance July 1, 1901, as per last report		$394.30

DISBURSEMENTS.

General expenses:		
Buildings	$110.61	
Fencing, etc	13.45	
Freight	179.08	
Machinery, etc	37.91	
Miscellaneous	13.31	
Surveying, plans, etc	25.00	
		379.36
Balance		14.94

Balance carried, under provisions of Revised Statutes, section 3090, by the Treasury Department to the credit of the surplus fund, June 30, 1902.

RECAPITULATION.

The total amount of funds administered by the Institution during the year ending June 30, 1902, appears from the foregoing statements and the account books to have been as follows:

SMITHSONIAN INSTITUTION.

From balance of last year, July 1, 1901	$83,963.26	
From interest on Smithsonian fund for the year	54,720.00	
From interest on West Shore bonds	1,680.00	
From sales of publications	301.85	
From repayments, freight, etc	10,109.24	
		$150,774.35

APPROPRIATIONS COMMITTED BY CONGRESS TO THE CARE OF THE INSTITUTION.

International exchanges—Smithsonian Institution:		
From balance of 1899–1900	$53.90	
From balance of 1900–1901	2,935.71	
From appropriation for 1901–2	24,000.00	
		$26,989.61
American Ethnology—Smithsonian Institution:		
From balance of 1899–1900	5.19	
From balance of 1900–1901	2,684.69	
From appropriation for 1901–2	50,000.00	
		52,689.88
Preservation of collections—National Museum:		
From balance of 1899–1900	331.39	
From balance of 1900–1901	6,507.92	
From appropriation for 1901–2	180,000.00	
		186,839.31
Furniture and fixtures—National Museum:		
From balance of 1899–1900	11.85	
From balance of 1900–1901	2,096.23	
From appropriation for 1901–2	20,000.00	
		22,108.08
Heating and lighting, etc.—National Museum:		
From balance of 1899–1900	.02	
From balance of 1900–1901	1,888.09	
From appropriation for 1901–2	23,000.00	
		24,888.11
Postage—National Museum:		
From appropriation for 1901–2		500.00
Printing—National Museum:		
From appropriation for 1901–2		17,000.00
Rent of workshops, etc.—National Museum:		
From balance of 1899–1900	.08	
From balance of 1900–1901	.08	
From appropriation for 1901–2	4,400.00	
		4,400.16
Building repairs—National Museum:		
From balance of 1899–1900	.85	
From balance of 1900–1901	884.93	
From appropriation for 1901–2	27,500.00	
		28,385.78
Galleries—National Museum:		
From appropriation for 1901–2		5,000.00

Books—National Museum:		
From balance of 1899–1900	$20.64	
From balance of 1900–1901	858.04	
From appropriation for 1901–2	2,000.00	
		$2,888.68
Purchase of specimens—National Museum:		
From balance of 1900–1901	3,058.56	
From appropriation for 1901–2	10,000.00	
		13,058,56
Astrophysical Observatory—Smithsonian Institution:		
From balance of 1899–1900	2.99	
From balance of 1900–1901	79.80	
From appropriation for 1901–2	12,000.00	
		12,082.79
Observation of eclipse of May 28, 1900:		
From balance July 1, 1901		755.74
National Zoological Park:		
From balance of 1899–1900	394.30	
From balance of 1900–1901	9,802.29	
From appropriation for 1901–2	80,000.00	
		90,196.59

SUMMARY.

Smithsonian Institution	$150,774.35	
Exchanges	26,989.61	
Ethnology	52,689.88	
Preservation of collections	186,839.31	
Furniture and fixtures	22,108.08	
Heating and lighting	24,888.11	
Postage	500.00	
Printing	17,000.00	
Rent of workshops	4,400.16	
Building repairs	28,385.78	
Galleries	5,000.00	
Books	2,888.68	
Purchase of specimens	13,058.56	
Astrophysical Observatory	12,082.79	
Observation of eclipse of May 28, 1900	755.74	
National Zoological Park	90,196.59	
		638,557.64

The committee has examined the vouchers for payment from the Smithsonian income during the year ending June 30, 1902, each of which bears the approval of the secretary or, in his absence, of the acting secretary, and a certificate that the materials and services charged were applied to the purposes of the Institution.

The committee has also examined the accounts of the several appropriations committed by Congress to the Institution, and finds that the balances hereinbefore given correspond with the certificates of the disbursing clerk of the Smithsonian Institution, whose appointment as such disbursing officer has been accepted and his bond approved by the Secretary of the Treasury.

The quarterly accounts current, the vouchers, and journals have been examined and found correct.

Statement of regular income from the Smithsonian fund available for use in the year ending June 30, 1903.

Balance July 1, 1902		$81,120.91
Interest due and receivable July 1, 1902	$27,360.00	
Interest due and receivable January 1, 1903	27,360.00	
Interest, West Shore Railroad bonds, due July 1, 1902	840.00	
Interest, West Shore Railroad bonds, due January 1, 1903	840.00	
		56,400.00
Total available for year ending June 30, 1903		137,520.91

Respectfully submitted.

J. B. HENDERSON,
ALEXANDER GRAHAM BELL,
ROBERT R. HITT,
Executive Committee.

WASHINGTON, D. C., *January 14, 1903.*

ACTS AND RESOLUTIONS OF CONGRESS RELATIVE TO THE SMITHSONIAN INSTITUTION, ETC.

[Continued from previous Reports.]

[Fifty-seventh Congress, second session.]

SMITHSONIAN INSTITUTION.

SMITHSONIAN DEPOSIT [LIBRARY OF CONGRESS].—For custodian, one thousand five hundred dollars; one assistant, one thousand two hundred dollars; one messenger, seven hundred and twenty dollars; one messenger boy, three hundred and sixty dollars; in all, three thousand seven hundred and eighty dollars. (Approved February 25, 1903; Statutes, XXXII, 864.)

EXCHANGE OF PUBLIC DOCUMENTS [LIBRARY OF CONGRESS].—For expenses of exchanging public documents for the publications of foreign governments, one thousand eight hundred dollars. (Approved February 25, 1903; Statutes, XXXII, 865.)

NATIONAL MUSEUM.

For cases, furniture, fixtures, and appliances required for the exhibition and safe-keeping of the collections of the National Museum, including salaries or compensation of all necessary employees, twenty-two thousand five hundred dollars.

For expense of heating, lighting, electrical, telegraphic, and telephonic service for the National Museum, eighteen thousand dollars.

For continuing the preservation, exhibition, and increase of the collections from the surveying and exploring expeditions of the Government, and from other sources, including salaries or compensation of all necessary employees, one hundred and eighty thousand dollars, of which sum five thousand five hundred dollars may be used for necessary drawings and illustrations for publications of the National Museum, and all other necessary incidental expenses.

For purchase of specimens to supply deficiencies in the collections of the National Museum, ten thousand dollars.

For purchase of books, pamphlets, and periodicals for reference in the National Museum, two thousand dollars.

For repairs to buildings, shops, and sheds, National Museum, including all necessary labor and material, fifteen thousand dollars.

For rent of workshops and temporary storage quarters for the National Museum, four thousand four hundred dollars.

For postage stamps and foreign postal cards for the National Museum, five hundred dollars. (Approved March 3, 1903; Statutes, XXXII, 1101, 1102.)

BUILDING FOR NATIONAL MUSEUM: To enable the Regents of the Smithsonian Institution to commence the erection of a suitable fireproof building with granite fronts, for the use of the National Museum, to be erected on the north side of the Mall, between Ninth and Twelfth streets northwest, substantially in accordance with the Plan A, prepared and submitted to Congress by the secretary of the Smithsonian Institution under the provisions of the act approved June twenty-eighth, nineteen hundred and two, two hundred and fifty thousand dollars. Said building complete, including heating and ventilating apparatus and elevators, shall cost not to exceed three million five hundred thousand dollars, and a contract or contracts for its completion is hereby authorized to be entered into subject to appropriations to be made by Congress. The construction shall be in charge of Bernard R. Green, superintendent of Buildings and Grounds, Library of Congress, who shall make the contracts herein authorized and disburse all appropriations made for the work, and shall receive as full compensation for his services hereunder the sum of two thousand dollars annually in addition to his present salary, to be paid out of said appropriations. (Approved March 3, 1903; Statutes, XXXII, 1102.)

For the Smithsonian Institution, for printing labels and blanks, and for the "Bulletins" and "Proceedings" of the National Museum, the editions of which shall not be less than three thousand copies, and binding, in half turkey, or material not more expensive, scientific books and pamphlets presented to and acquired by the National Museum Library, seventeen thousand dollars. (Approved March 3, 1903; Statutes, XXXII, 1146.)

For preservation of collections, National Museum, sixty cents. (Approved March 3, 1903; Statutes, XXXII, 1075.)

INTERNATIONAL EXCHANGES.

For expenses of the system of international exchanges between the United States and foreign countries, under the direction of the Smithsonian Institution, including salaries or compensation of all necessary employees, and the purchase of necessary books and periodicals, twenty-six thousand dollars. (Approved March 3, 1903; Statutes, XXXII, 1101.)

GEOLOGICAL SURVEY.—For the purchase of necessary books for the library, including directories and professional and scientific periodicals needed for statistical purposes, not to exceed two thousand dollars, and the payment for the transmission of public documents through the Smithsonian exchange, four thousand dollars; in all, six thousand dollars. (Approved March 3, 1903; Statutes, XXXII, 1118.)

NAVAL OBSERVATORY.—For repairs to buildings, fixtures, and fences, furniture, gas, chemicals, and stationery, freight (including transmission of public documents through the Smithsonian exchange), foreign postage, and expressage, plants, fertilizers, and all contingent expenses, two thousand five hundred dollars. (Approved February 25, 1903; Statutes, XXXII, 889.)

BUREAU OF AMERICAN ETHNOLOGY.

For continuing ethnological researches among the American Indians, under the direction of the Smithsonian Institution, including salaries or compensation of all necessary employees and the purchase of necessary books and periodicals, forty thousand dollars, of which sum not exceeding one thousand five hundred dollars may be used for rent of building. (Approved March 3, 1903; Statutes, XXXII, 1101.)

NATIONAL ZOOLOGICAL PARK.

For continuing the construction of roads, walks, bridges, water supply, sewerage and drainage; and for grading, planting, and otherwise improving the grounds; erecting and repairing buildings and inclosures; care, subsistence, purchase, and transportation of animals; including salaries or compensation of all necessary employees, the purchase of necessary books and periodicals, the printing and publishing of operations, not exceeding one thousand five hundred copies, and general incidental expenses not otherwise provided for, ninety-five thousand dollars; one-half of which sum shall be paid from the revenues of the District of Columbia and the other half from the Treasury of the United States. (Approved March 3, 1903; Statutes, XXXII, 1102.)

For Adams Mill road, Columbia road to Zoo, grade and improve, seven thousand dollars. (Approved March 3, 1903; Statutes, XXXII, 963.)

That in order to more fully carry out the intent of the provision in the appropriation act approved July first, nineteen hundred and two, providing for the expenses of the government of the District of Columbia, authorizing the readjustment of the lines of the streets on the east side of the Zoological Park, the Commissioners of the District of Columbia be, and they are hereby, authorized to use as a highway so

much of the Zoological Park as lies within a proposed street on the east side of said Zoological Park between Kenyon street and Klingle road, the bounds of said street being located as follows: The east building line to be distant fifteen feet from the present improved thirty-foot roadway and the west line to be distant forty-five feet from the present improved thirty-foot roadway. (Approved March 3, 1903; Statutes, XXXII, 963.)

ASTROPHYSICAL OBSERVATORY.

For maintenance of Astrophysical Observatory, under the direction of the Smithsonian Institution, including salaries of assistants, the purchase of necessary books and periodicals, apparatus, making necessary observations in high altitudes, printing and publishing results of researches, not exceeding one thousand five hundred copies, repairs and alterations of buildings and miscellaneous expenses, fifteen thousand dollars. (Approved March 3, 1903; Statutes, XXXII, 1101.)

ILLUSTRATIONS IN GOVERNMENT DOCUMENTS.

That no part of the appropriations herein made for printing and binding shall be used for any illustration, engraving, or photograph, in any document or report ordered printed by Congress unless the order to print expressly authorizes the same, nor in any document or report of any Executive Department or other Government establishment until the head of the Executive Department or Government establishment shall certify in the letter transmitting such report that the illustration is necessary and relates entirely to the transaction of public business. (Sundry civil act, approved March 3, 1903; Statutes, XXXII, 1147.)

REPORT

OF

S. P. LANGLEY,

SECRETARY OF THE SMITHSONIAN INSTITUTION,

FOR THE YEAR ENDING JUNE 30, 1902.

To the Board of Regents of the Smithsonian Institution.

GENTLEMEN: I have the honor to present herewith my report showing the operations of the Institution during the year ending June 30, 1902, including the work placed under its direction by Congress in the United States National Museum, the Bureau of American Ethnology, the International Exchanges, the National Zoological Park, and the Astrophysical Observatory.

Following the precedent of several years, there is given, in the body of this report, a general account of the affairs of the Institution and its bureaus, while the appendix presents more detailed statements by the persons in direct charge of the different branches of the work. Independently of this, the operations of the National Museum are fully treated in a separate volume of the Smithsonian Report, and the Report of the Bureau of American Ethnology constitutes a volume prepared under the supervision of the Director of that Bureau.

THE SMITHSONIAN INSTITUTION.

THE ESTABLISHMENT.

By act of Congress approved August 10, 1846, the Smithsonian Institution was created an Establishment. Its statutory members are the President, the Vice-President, the Chief Justice of the United States, and the heads of the Executive Departments. The prerogative of the Establishment is "the supervision of the affairs of the Institution and the advice and instruction of the Board of Regents."

On the death of President McKinley on September 14, 1901, Vice-President Roosevelt succeeded to the Presidency and a vacancy occurred in the vice-presidency. Other changes were caused by the resignation of the Hon. Lyman J. Gage, Secretary of the Treasury;

the Hon. John D. Long, Secretary of the Navy, and the Hon. Charles Emory Smith, Postmaster-General.

As organized on June 30, 1902, the Establishment consisted of the following ex officio members:

THEODORE ROOSEVELT, *President of the United States.*
(Vacancy), *Vice-President of the United States.*
MELVILLE W. FULLER, *Chief Justice of the United States.*
JOHN HAY, *Secretary of State.*
LESLIE M. SHAW, *Secretary of the Treasury.*
ELIHU ROOT, *Secretary of War.*
PHILANDER C. KNOX, *Attorney-General.*
HENRY C. PAYNE, *Postmaster-General.*
WILLIAM H. MOODY, *Secretary of the Navy.*
ETHAN ALLEN HITCHCOCK, *Secretary of the Interior.*
JAMES WILSON, *Secretary of Agriculture.*

BOARD OF REGENTS.

The Board of Regents consists of the Vice-President and the Chief Justice of the United States as ex officio members, three members of the Senate, three members of the House of Representatives, and six citizens, "two of whom shall be residents of the city of Washington and the other four shall be inhabitants of some State, but no two of them of the same State."

In accordance with a resolution of the Board of Regents adopted January, 1890, by which its annual meeting occurs on the fourth Wednesday of each year, the Board met on January 22, 1902, at 10 o'clock a. m.

The following is an abstract of its proceedings, which will be found in detail in the annual report of the Board to Congress:

The Secretary stated that Vice-President Roosevelt had been ex officio a member of the Board, but that by reason of his succession to the Presidency through the death of President McKinley his membership upon the Board had ceased, and he had become the presiding officer of the Institution. In accordance with precedent, an invitation had been extended to the President pro tempore of the Senate, the Hon. William P. Frye, to attend the meeting in place of the Vice-President.

He announced the reappointment, as Regents, of Representatives R. R. Hitt, Robert Adams, jr., and Hugh A. Dinsmore, whose terms had expired.

The Secretary presented his report of the operations of the Institution for the fiscal year ending June 30, 1901, inviting the Board's attention to the statements concerning the National Zoological Park, the International Exchange Bureau, and the other interests under their charge. He spoke particularly with regard to the crowded condition of the National Museum, the need for additional space for the

exhibition and care of the increasing collections, and the need of special action to secure it.

After discussion, the following resolution was adopted:

Resolved, That a committee consisting of six members of this Board be appointed by the Chancellor, whose duty it shall be to represent to Congress the pressing necessity of additional room for the proper exhibition of specimens belonging to the National Museum, and of additional appropriations to carry on the work of the Museum.

The Chancellor appointed as members of this committee Senators Platt, Cullom, and Cockrell, and Representatives Hitt, Adams, and Dinsmore.

The Board adopted the annual reports of the executive and permanent committees, which had been presented by their chairman, Senator Henderson. The usual resolution relative to income and expenditure was adopted.

The Secretary read a letter from the authorities of the British burial ground at Genoa, stating that when the time arrived for the abolition of the cemetery by the Italian Government and the transfer of the bodies there to a new site, the remains of Smithson would be reinterred with due reverence and care.

Mr. Bell said that he would like very much to have the records show that he had presented to the Board at the last meeting an expression of his strong feeling that the remains of Smithson should be brought to this country.

The Secretary said that the governor of New Mexico had offered to transfer to the Institution an ancient Spanish palace in Santa Fe, on condition that it be maintained, without cost to the State, as a museum of the archæology of the Southwest. After discussion the Board decided that it was inadvisable to accept the proposition.

The Secretary said that since the foundation of the Smithsonian Institution there had perhaps occurred no event of more importance to it than the foundation of a new institution—the Carnegie Institution—whose declared aims and general purposes were nearly those which the Institution has hitherto considered its own. Mr. Carnegie invited the Secretary of the Smithsonian to become a member of the board of trustees for the management of this fund, in the following letter:

DECEMBER 27, 1901.

DEAR SIR: I am about to transfer ten millions of 5 per cent bonds to a body of trustees for the purposes described in the inclosed paper. A list of the trustees selected is also inclosed

It will be a source of much pleasure to me if you will kindly consent to serve.

Truly yours, ANDREW CARNEGIE.

THE SECRETARY OF THE SMITHSONIAN INSTITUTION.

The letter was accompanied by a list of the trustees and by a statement of the considerations which led to the establishment of the foundation. The Secretary read the articles of incorporation of the new

institution, and stated that after conference with the Chancellor and the chairman of the executive committee, he had accepted the trusteeship in the following terms, conditionally on the approval of the board:

DECEMBER 31, 1901.

DEAR SIR: I beg to acknowledge the receipt of your communication of the 27th instant, with the accompanying papers outlining the general purpose of an institution or establishment which you propose to found in the city of Washington for the encouragement of research and kindred purposes, and also inclosing a list of proposed trustees, in which you are good enough to name the Secretary of the Smithsonian Institution as an ex officio member.

It will give me, personally, great pleasure, with the consent of the Regents, to accept membership upon this board, and I desire to express my sense of warm recognition of the large purposes which have inspired you to make this noble benefaction. I accept such membership in the absence of knowledge as to details, but in the full confidence of a sympathy with your general purpose.

Very respectfully, yours,

S. P. LANGLEY,
Secretary.

ANDREW CARNEGIE, Esq.,
No. 5 West Fifty-fifth Street, New York City.

He then stated certain considerations with regard to the relationship of the Smithsonian Institution to the Carnegie Institution, and asked for an expression of the opinions of the Regents for his instruction. After discussion, it was announced as the sense of the Board that the Secretary should accept the trusteeship unfettered by instructions.

The Secretary then spoke of the affairs of the Bureau of Ethnology, and of the Astrophysical Observatory, whose first volume of the Annals he exhibited. With regard to the Observatory, the Secretary said further that Congress had asked for a report of the appropriations granted it and of the results obtained. Such a report had been submitted at the beginning of the session, and had been ordered printed. It included the Annals above referred to, and he had been enabled to add a number of commendatory letters from eminent men of science, such as Sir George Stokes, Lord Rayleigh, Lord Kelvin, Sir William Huggins, Sir Robert Ball, Prof. Simon Newcomb, Prof. E. C. Pickering, Prof. G. E. Hale, and others.

ORGANIZATION OF BOARD OF REGENTS.

As organized at the end of the fiscal year, the Board of Regents consisted of the following members:

The Hon. M. W. Fuller, Chief Justice of the United States, Chancellor; the Hon. W. P. Frye, President pro tempore of the United States Senate; Senator S. M. Cullom; Senator O. H. Platt; Senator Francis M. Cockrell; Representative R. R. Hitt; Representative Robert Adams, jr.; Representative Hugh A. Dinsmore; Dr. James B. Angell; Dr. Andrew D. White; the Hon. J. B. Henderson; Prof. A. Graham Bell; the Hon. Richard Olney, and the Hon. George Gray.

ADMINISTRATION.

The general supervision of the business of the several dependencies placed by Congress under the direction of the Institution has year by year required the increased personal attention of the Secretary, although as far as seems practicable the carrying out of details has been left to those in immediate charge of the work of the bureaus. The cost of the clerical labor involved in this general supervision by the Secretary's office is in part met by allotments from the various Government appropriations, although the limited income of the Institution is still drawn upon for many matters which should properly be provided for by Congress.

The Board has authorized the Secretary to lay these matters before Congress, but the needs of other parts of the Institution's service have seemed so pressing that he has as yet deferred doing so in favor of such other demands.

BUILDINGS.

Some much-needed repairs to the main roof of the Smithsonian building were in progress at the close of the fiscal year. In this connection it seems important to call attention to the necessity of a reconstruction of the ceiling and other renovations of the large Anthropological Hall, whose noble dimensions deserve a worthier treatment, and of improving the access to it.

Improvements were made in the Smithsonian basement in the quarters occupied by the Exchange Office and a hydraulic elevator was constructed for the handling of heavy packages.

In the paragraphs devoted to the Museum and to the Zoological Park mention is made of building improvements during the year.

FINANCES.

At the beginning of the fiscal year, July 1, 1901, the unexpended balance, as stated in my last report, was $83,963.26. During the year the total receipts by the Institution were $66,811.09. Of this sum $56,400 was derived from interest, while the remaining $10,411.09 was received from miscellaneous sources.

The disbursements during the year amounted to $69,653.44, the details of which are given in the report of the executive committee. The balance remaining to the credit of the Secretary on June 30, 1902, for the expenses of the Institution was $81,120.91. A considerable part of this balance is held against the accumulated interest on the Hodgkins and other funds and against certain contingent obligations which may be expected to mature as a result of various scientific investigations and publications in progress.

The permanent funds of the Institution are as follows:

Bequest of Smithson, 1846		$515,169.00
Residuary legacy of Smithson, 1867		26,210.63
Deposits from savings of income, 1867		108,620.37
Bequest of James Hamilton, 1875	$1,000.00	
Accumulated interest on Hamilton fund, 1895	1,000.00	
		2,000.00
Bequest of Simeon Habel, 1880		500.00
Deposits from proceeds of sale of bonds, 1881		51,500.00
Gift of Thomas G. Hodgkins, 1891		200,000.00
Portion of residuary legacy of Thomas G. Hodgkins, 1894		8,000.00
Total permanent fund		912,000.00

The above fund is deposited in the Treasury of the United States, under the provisions of the act organizing the Institution and the act of Congress approved March 12, 1894, and bears interest at 6 per cent per annum. The interest alone is employed in carrying out the aims of the Institution. The Regents hold certain approved railroad bonds, in addition to the permanent fund, which form part of the fund established by Mr. Hodgkins for investigations into the properties of atmospheric air.

The Institution was charged by Congress, during the fiscal year of 1902, with the disbursement of the following appropriations:

International Exchanges, Smithsonian Institution		$24,000
American Ethnology, Smithsonian Institution		50,000
Astrophysical Observatory, Smithsonian Institution		12,000
United States National Museum:		
Furniture and fixtures	$20,000	
Heating and lighting	23,000	
Preservation of collections	180,000	
Purchase of specimens	10,000	
Postage	500	
Books	2,000	
Rent of workshops	4,400	
Repairs to buildings	27,500	
Galleries	5,000	
Printing	17,000	
		289,400
National Zoological Park		80,000
Total		455,400

Estimates were forwarded as usual to the Secretary of the Treasury for carrying on the Government's interests under charge of the Smithsonian Institution for the fiscal year ending June 30, 1903. The following table shows the estimates and the sums respectively appropriated:

	Estimates.		Appropriations.	
International Exchanges	[a] $26,000		$26,000	
American Ethnology	60,000		50,000	
Astrophysical Observatory	15,000		15,000	
National Museum:				
Furniture and fixtures	$25,000		$22,500	
Heating and lighting	18,000		18,000	
Preservation of collections	200,000		180,000	
Purchase of specimens	25,000		10,000	
Books	5,000		2,000	
Repairs to buildings	15,000		15,000	
Rent of workshops	4,400		4,400	
Postage	500		500	
Plans for additional fireproof building	5,000		5,000	
Contributions from National Museum Herbarium	7,000		7,000	
Printing	17,000	321,900	17,000	281,400
National Zoological Park	110,000		90,000	
Aquarium	25,000			
Elephant house	20,000	155,000	10,000	100,000
Total		577,900		472,400

[a] Not including supplementary estimate of $3,800 submitted February 12, 1902.

RESEARCH.

It was a part of the original plan of the Institution that its Secretary should not give his time wholly to administrative duties, but should, as a student of nature, directly aid in its scientific investigations.[b]

Research work in various fields of science has been continued by the Institution and its dependencies. The Secretary has made some progress toward the solution of the problem of mechanical flight, and has been carrying on, with the consent of the Regents, some experiments for the War Department, at its expense, and is adding other experiments, partly at the expense of the Institution. In the Astrophysical Observatory he has continued work believed to be important, and inaugurated some experiments of novel interest, which are referred to later.

Through the Museum and the Bureau of American Ethnology the Institution has been enabled to carry on various biological and ethnological researches, which will be found fully described elsewhere in this report and need not be repeated here.

HODGKINS FUND.

In connection with the administration of the Hodgkins fund, papers recording the advance of specialists along various interesting lines of investigation have been submitted, some of which are now in course of publication.

[b] *Resolved*, That the Secretary continue his researches in physical science, and present such facts and principles as may be developed for publication in the Smithsonian contributions. (Adopted at meeting of the Board of Regents January 26, 1847.)

The report of the research on the spectrum conducted by Dr. Victor Schumann, of Leipzig, has received extensive additions during the year, notably through a detailed description of the ingenious apparatus used in his work. This supplement is accompanied by illustrations which appear now for the first time, although Dr. Schumann has been authorized to announce in the scientific journals of his own country the discoveries made in the course of his experiments, at the same time notifying the Institution of his progress.

A second grant on behalf of Dr. Schumann has been approved during the year, and it is interesting to know that Harvard University, recognizing the value of his work, has also awarded him a grant. The new Physical Institute of the Royal Academy of Sciences in Leipzig has likewise aided this research by placing laboratory room at the disposal of Dr. Schumann, who, it is hoped, will be able in the near future to secure still more complete results from his painstaking experiments in vacuum spectroscopy.

The memoir by Dr. Carl Barus, mentioned in my last report as in course of publication, has been issued during the year as part of Volume XXIX, Smithsonian Contributions to Knowledge. It describes experiments with ionized air begun by Dr. Barus some years since and recently prosecuted under a Hodgkins grant from the Institution. The research was tributary to an investigation of the colors of cloudy condensation. Lord Rayleigh's famous theory, if applied, would stop at the deep reds of the first order, terminating in opaque, whereas in the laboratory experiments exceptionally brilliant colors, extending almost into the third order of Newton's series, may be produced. It was thus essential as a preliminary step to investigate appropriate means for the production of nuclei, to determine their number per cubic centimeter, their velocity, their association with ionization, the effect of the pressure of an electric field, etc. This was the general trend of the experiments by Dr. Barus. The endeavor was made with the aid of the condensation tube to show that the nucleus has a specific velocity of its own, and that this is retained even in the absence of an electric field. The application of this principle to plate, to tubular, and to spherical condensers leads, in every case and in spite of the variation of method, to an order of values as to the number of particles in action, agreeing with the data obtained by other investigators from different experiments and theoretically different points of view.

A second grant has been approved on behalf of Dr. Barus, and a new memoir on the structure of the nucleus, detailing experiments subsequent to those described in the volume just published is soon to be submitted by him.

The experiments in air resistance by Mr. C. Canovetti, referred to in the Secretary's last report, which were begun at Brescia, Italy, of

which city he was at that time engineer in chief, have been continued in Italy, where by means of an ingenious apparatus he has prosecuted a research which has been reported upon in detail, with illustrations accompanied by tables giving the numerical results attained. After compliance with the request of the Institution in regard to submitting his report, a second moderate grant was approved on behalf of Mr. Canovetti in March of this year. A report of the results of the experiments under this second grant is now awaited.

Dr. von Lendenfeld, of the University of Prague, who has been aided by a grant from the Hodgkins fund, reports that his studies are now sufficiently advanced to enable him to begin the preparation of his manuscript for publication. Telephotography has been extensively and successfully used in this research, and the summary of work already submitted is accompanied by interesting illustrations.

A monograph embodying the results of the completed research, which will be published later, will present an anatomical and physiological study of insects, the lower vertebrates (Exocœtus, Draco, etc.), birds, mammals (Petaurus, Geleopithecus, etc.), and will treat of the polygenetic development of the organs of flight in animals. The physical properties of the air, wind velocities, resistance, etc., will be considered, and it is hoped that the publication will not only prove of general interest but will become a valuable work of reference for students.

Dr. Marey, of the French Institute, mentioned in my last report as having been awarded a grant from the Hodgkins fund, is still continuing his most interesting experiments. The application of metrophotography and chronophotography to this investigation has been described by Dr. Marey in a paper of such general value that it was published in the appendix to the report of the Secretary for 1901. In this edition of the paper are included copies of special and interesting photographs which have been forwarded to the Institution by Dr. Marey.

The research into the nature of vowels by Prof. Louis Bevier, of Rutgers College, has been reported on through a series of published articles, transmitted by the author to the Institution, which record in detail the results thus far obtained. The investigation is still in progress, the vowel series from a to u being now under analysis and discussion.

During this year a grant has been approved on behalf of Mr. E. C. Huffaker for the construction and practical application of a device intended to produce a uniform and measured flow of air through a tube of any desired diameter.

This apparatus is primarily designed for use in connection with investigations in the line of biology, and it has already been applied

to exact experiments in the development of the embryo in the egg. It is hoped that by means of this invention facts may be established which will prove of practical value.

The meteorological investigation in connection with air currents at varying altitudes, heretofore reported on as conducted by Mr. A. L. Rotch at Blue Hill Meteorological Observatory, have been supplemented this year by a series of experiments on the lift and drift of the wind on plane and curved surfaces. Mr. A. A. Merrill, who was recommended by Mr. Rotch for this work, received a grant from the Hodgkins fund and has from time to time reported the result of his experiments.

The grant to the Journal of Terrestrial Magnetism and Atmospheric Electricity has been continued during the past year, a specified number of copies of the Journal being sent out, as directed by the Institution, to specialists and to educational establishments.

In May, 1902, an application for a grant from the Hodgkins fund was made by Prof. Morris W. Travers, of University College, London, which, after the customary reference, examination, and discussion, was approved in June of this year. Professor Travers has been the colleague of Prof. William Ramsey in his later researches upon the rare gases of the atmosphere, and is now engaged in an investigation which will deal largely with the liquid properties of hydrogen.

A summary of the progress of this investigation, on behalf of which the final grant of this year is approved, will find place in the next report.

The difficulties in the way of submitting, during the progress of a research, a report which is even measurably satisfactory to an investigator, are appreciated by the Secretary, whose duty it becomes, year by year, to record so far as possible the advance of the investigations which the terms of the bequest allow him to aid by grants from the Hodgkins fund.

In November, 1901, a special committee, the members of which represented the departments of biology, physics, chemistry, geology, meteorology, astronomy, electricity, and anthropology, was appointed to consider the award of the Hodgkins special medal, which, as stated in the report for 1899, is bestowed only for important contributions to the knowledge of the nature and properties of atmospheric air, or for original and practical applications of present knowledge to the welfare of mankind, thus complying not only with the terms of the Hodgkins Fund, but also furthering the expressed aim of the founder of the Institution.

As will be remembered, the first special Hodgkins medal was awarded in 1899 to Prof. James Dewar, of the Royal Institution of Great Britain.

In accordance with the recommendation of the committee, the

present award is made to Prof. J. J. Thomson, of Trinity College, Cambridge, England, and is, broadly stated, for his investigations on the conductivity of gases, especially on the gases that compose atmospheric air.

NAPLES TABLE.

The lease by the Institution, for a third term of three years, of a table in the Naples Zoological Station, which expired on the 30th of June, 1902, has been extended until the 31st of December of the same year. Following this action, numerous applications for the Smithsonian seat, which had necessarily been held pending, were taken up for consideration. The question as to the renewal of the lease for another term of years is now receiving careful consideration, and will be decided before the expiration of the present contract.

The Secretary visited the Naples Station during the summer and was pleased with the investigations carried on there. The Smithsonian Institution, through its cooperation in this work, has been brought in touch with many institutions of learning in the United States, but it is to be hoped that it may receive from some extraneous source the means of continuing this lease for the benefit of all American biologists, which if renewed must divert to this useful but extraneous purpose funds needed for others.

In November, 1901, Dr. C. W. Prentiss, to whom a traveling Parker Fellowship had been awarded by Harvard University, applied for and received the appointment to the Smithsonian seat in the Naples Station for March, April, and May, 1902. Being reappointed Parker Fellow while in residence at Naples, Dr. Prentiss asked for a prolongation of his term through the months of June and July. The unavoidable delay in replying to this request, caused by the uncertainty as to the extension of the lease, was not allowed to work to the disadvantage of the applicant by Dr. Dohrn, who kindly invited him to continue his occupancy until a decision was reached by the Institution.

Numerous other applicants were also, to my regret, kept in uncertainty in regard to their appointments, but although this fact finally brought three and even four Smithsonian appointees to Naples at the same time, and for an extended period, they were all courteously arranged for by the obliging director of the station. The details of these appointments will receive mention in the report for the coming year, to which they belong and are accredited. It may be added that numerous applications, for periods beyond the present extension of the lease, are now held for action, awaiting a decision as to its renewal.

The Secretary desires to express again his appreciation of the ready and efficient aid rendered him year after year by the advisory committee in the examination of credentials and in recommendations as to appointments.

EXPLORATIONS.

The Institution has continued to carry on various biological and ethnological explorations through the medium of the National Museum and the Bureau of American Ethnology, and has also cooperated with the Executive Departments in these directions. The details of most of these explorations are given in the paragraphs devoted to the several bureaus.

PUBLICATIONS.

In the publications of the Institution the double aim of its founder is represented—that it should exist for (1) the "increase" and (2) the "diffusion" of knowledge.

The recording of results of original researches, the *increase* of knowledge, is chiefly through the series of Contributions to Knowledge, a quarto work begun in 1848, and in which more than 140 valuable memoirs, collected in 32 volumes, have so far been published. To this series has been added during the year a memoir by Dr. Carl Barus giving the results of his experiments in ionized air, the investigation having been aided by a grant from the Hodgkins fund, as mentioned above.

The first edition of one of the memoirs of Contributions, published in 1891, showing the results of the Secretary's experiments in aerodynamics, having become exhausted, a second edition has been printed from the stereotype plates, with a few additional observations.

To the series of Miscellaneous Collections, in octavo form, have been added a List of Observatories, a work on the Literature of Manganese, and an Index to the Literature of the Spectroscope.

The Contributions and Miscellaneous Collections, being printed at the expense of the Smithsonian income, are necessarily published in limited editions of 1,500 copies, which are distributed as widely as possible to the larger libraries and institutions of the world. The total distribution of these during the year was 11,645 volumes and memoirs.

The Smithsonian Report is the only publication issued in large numbers, the edi ion being at present about 12,000 copies, 7,000 of which are placed at the disposal of the Institution, the remaining 5,000 being distributed by Congress or to depositories designated by law. This work is published at the expense of the Government and has come to be in such great popular demand that the entire edition of the 1900 report, of which the general distribution was made in October, 1901, was exhausted in a few months, even before the 1901 report could be made ready for the printer.

The volume is primarily a Report of the Board of Regents to Congress concerning the operations and expenditures during the year, and includes the Proceedings of the Regents' meeting in January of each year, the financial report of the executive committee, the report of

the Secretary, giving an account of the year's work, and a general appendix. Its appendix, however, forms a distinct and popular part of the work and is one of the principal methods employed by the Institution in the *diffusion* of knowledge. In the appendix are published a large number—sometimes as many as 50—papers of public interest.

The Secretary has said elsewhere: "These papers have a purpose distinct from any others published by the Institution. They are only occasionally original contributions to science. They are not for the professional reader only, or even chiefly, but they are addressed to that large body of the public which has a general interest in scientific matters without special knowledge. While it is always a recommendation that they should have been written by recognized authorities, yet this is of minor importance if the articles are sound expositions of the subject. The essential thing is that they should be not only sound and instructive, but timely and interesting to the nonprofessional reader, and in that good sense popular. If they are accompanied by illustrations, all the better. As they are intended to serve as a kind of popular survey of the whole field of the sciences, both physical and biological, for the current year, it is, as a rule, impracticable to print more than one paper on any particular subject."

A portion of the edition of the report is distributed in the form of pamphlets of individual papers, and where any of these are of particular interest additional copies are printed at the expense of the Institution. Of the 1901 report 23,750 copies of separate papers have thus been ordered for special distribution.

It is impossible to meet the great demand from individuals for the reports, more than 5,000 copies being required to supply a selected list of libraries and institutions of learning, to which the work has been regularly sent for many years. The total distribution of volumes or separate parts of reports during the past fiscal year aggregated 40,998.[a]

This publication, then, is distributed not only to a large number of libraries throughout the world, but it is also addressed to as many as possible of the hundreds of individual applicants of all classes who seem eager to learn of the world's advance in the several branches of

[a] Sent to—

	Volumes.	Separate papers.
Domestic libraries	4,529	18,606
Foreign libraries	2,011	6,088
Domestic periodicals	436	28
Foreign periodicals	790	30
Domestic individuals	2,381	5,101
Foreign individuals	154	844
Total	10,301	30,697

knowledge. It is by these reports, which are in a good sense popular, as well as by its original scientific works, that the Institution grows each year better known as one of those whose influence for good is limited by no boundary, but, as its motto declares, goes "throughout the world." In this the Secretary has for some years past imitated the action of his honored predecessor, Henry, in giving a great deal of his personal attention to its editorship, with a view to making it of more popular interest, and he has been gratified at the large demand just referred to, with which the result of his labors has been met.

In addition to the preceding publications by the Institution proper, a considerable number of works, chiefly on biological topics, have been added to the Museum series.

Of the publications of the Bureau of American Ethnology, the second part of the Eighteenth Report for the fiscal year 1896–97 was distributed, also the separate papers of the Nineteenth Report for 1897–98. The manuscripts of the Twentieth, Twenty-first, and Twenty-second Reports for the years 1899 to 1901 were transmitted to the printer during the last half of the fiscal year.

Mention may also be made of a special edition of Volume I of the Annals of the Astrophysical Observatory, reprinted from a Senate document of which it formed a part. This document[a] consisted of a volume of 339 pages and 44 plates, submitted to Congress in response to the following item in the sundry civil act of March 3, 1901: "That the Secretary of the Smithsonian Institution is directed to report to Congress on the first day of the next regular session an entire account of all appropriations heretofore expended by the Astrophysical Observatory, what results have been reached, and what is the present condition of the work of said Observatory."

The Secretary during the year transmitted to Congress the Annual Report of the American Historical Association for the year 1901, and also the Fourth Report of the National Society of the Daughters of the American Revolution. The Institution has no share in the distribution of the latter report, only the "usual" document number (1,682) being printed. Of the Historical Reports a limited number, beginning with the 1894 report, have been at the disposal of the Institution for distribution to the larger historical societies of the world in exchange for their publications.

LIBRARY.

The accessions to the Smithsonian deposit in the Library of Congress during the year were 1,678 volumes, 20,834 parts of volumes, 3,732 pamphlets, and 414 charts, or a total of 26,658, extending the accession numbers to 445,523. The libraries of the Secretary's office, and of

[a] Senate Document No. 20, Fifty-seventh Congress, first session.

the Astrophysical Observatory were also increased by 496 volumes and 2,587 parts of volumes.

A very complete and valuable collection of books and pamphlets relating to Napoleon Bonaparte has been presented to the Institution by Gen. John Watts de Peyster, and will be known as the "Watts de Peyster Collection, Napoleon Bonaparte." The 2,000 volumes in this series are from many countries and in many languages.

The Smithsonian Art Room, placed in general charge of the librarian, has been made attractive by a rearrangement of the cases containing the valuable engravings and books on art belonging to the Institution, and steps have been taken for exhibiting a reproduction of the Parthenon frieze around the entire room.

Several years ago the Secretary organized an employees' library, which has proved to be very popular, and a branch has been established in the National Zoological Park.

The accessions to the National Museum Library were 19,553 books, pamphlets, and periodicals. Its crowded condition has been relieved by the addition of galleries, making a total floor space of 2,592 square feet. Thirty sectional libraries are established in the departments of the Museum, thus making readily accessible to those in charge of the several branches of scientific research the books directly pertaining to their work, while the administration of these sectional libraries is under the control of the Museum librarian.

Since the Secretary's last report, considerable work has been done in the maintenance of the International Catalogue of Scientific Literature, an allotment from the Institution's fund permitting the establishment of a regional bureau. An annual appropriation of about $10,000 is needed for the United States Regional Bureau, and it is hoped that Congress may provide such an amount for the accomplishment of this undertaking, so important to every branch of scientific learning, a work that no single institution could be expected to carry forward. The importance of the catalogue and the methods of its preparation have been fully explained in previous reports.

CORRESPONDENCE.

Though the correspondence of the Institution has increased during the year, it has been promptly dispatched and the routine is not in arrears. This correspondence embraces not only communications referring to the work of the Institution proper, but also to the National Museum, the International Exchanges, the Bureau of American Ethnology, the National Zoological Park, and the Astrophysical Observatory. Such matters as require the personal attention of the Secretary, or relate to the business of the parent Institution are retained in the Institution, while communications relating to the work of the bureaus

are referred to the proper officials for recommendations to the Secretary or for direct reply.

The system of recording and distributing letters has been unchanged since 1890, except in a few unimportant particulars. Every letter receives a reply, which is sent as promptly as the circumstances may allow. The matters of inquiry are perhaps more varied and embrace a wider range of topics than obtains in other departments of the Government. A register is kept of such letters as are of importance, in which is noted in each instance the date of the letter, its subject, the official to whom referred for attention, the date of reply, and the place of filing. The letters are filed alphabetically, with a notation of each on a card catalogue, giving a brief synopsis of its contents. The papers relating to certain special matters are kept separately in a series of smaller file boxes.

In preparing the correspondence involved in the distribution of publications much labor is saved by the use of printed mailing cards, often requiring only the insertion of the name and address of the person for whom intended.

The correspondence relating to civil-service matters has grown steadily since the bureaus of the Institution were placed under the operation of the civil-service law in 1896, and a separate series of press-copy books and a separate file of letters relating to such matters are kept, as well as a special file for the reception of papers not relating directly to the personnel of the several bureaus.

EXPOSITIONS.

Buffalo and Charleston expositions.—The Institution and its bureaus participated in the Pan-American Exposition held at Buffalo from May 1 to November 1, 1901, and by authority of the President the exhibits there displayed were transferred to the South Carolina Interstate and West Indian Exposition held at Charleston from December 1, 1901, to May 31, 1902. Dr. F. W. True, of the National Museum, was appointed by the Secretary to represent the Institution on the board in charge of the Government exhibits at both these expositions, and his report on the Buffalo Exposition will be found in the Appendix.

Louisiana Purchase Exposition.—Congress having made an appropriation for a Government building and exhibit at the exposition to be held in St. Louis in 1904, the Secretary has appointed Dr. True to represent the Institution and its bureaus in the preparation and installation of the exhibits.

MISCELLANEOUS.

Baird statue.—Several petitions having been presented to the Senate at its last session for the erection of a statue to Prof. Spencer

F. Baird, the second Secretary of this Institution, and an eminent naturalist, it seems proper to recall that a bill was introduced in the Senate on December 12, 1887, by Senator Morrill appropriating the sum of $15,000 for a statue in bronze of Professor Baird. The bill was referred to the Senate Committee on Public Buildings and Grounds, from which it was reported on December 21 of the same year, and passed by the Senate on February 9, 1888. On February 13 it was referred to the House Committee on the Library, from which it failed of report.

Senator Morrill afterwards reported for the Committee on Public Buildings and Grounds an amendment to the sundry civil bill for 1890, appropriating the sum above mentioned for the erection of the statue. The amendment was referred to the Senate Appropriations Committee, but was not included in the bill as reported from the committee.

The Secretary called attention to the matter in his reports for the years 1889, 1890, 1891, 1892, and 1894, where the hope was expressed that the bill would receive favorable consideration.

National gallery of American art.—A bill having been introduced in Congress at its last session for the construction of a national gallery of art, the attention of Senator Penrose, who presented the bill, was called to the fact that section 5586 of the Revised Statutes specifies, among other things, that whenever suitable arrangements can be made from time to time for their reception, all objects of art belonging to the United States shall be delivered to such persons as may be authorized by the Board of Regents of the Smithsonian Institution to receive them, and so arranged and classified in the building erected for the Institution as best to facilitate their examination and study. In compliance with this provision of law the Institution has for many years maintained a collection of art objects, to which has been added from to time, by gift and purchase, paintings, bronzes, etc., though with its limited fund the acquisitions by purchase have not been numerous. It was suggested to Senator Penrose that should there be any likelihood of the passage of the bill the Smithsonian Institution, which has always concerned itself with art, would be the natural custodian of a national gallery. The bill is still pending, and will probably come up for action during the next session of Congress.

International Zoological Congress.—At the Fifth International Zoological Congress held in Berlin, Germany, August 12–16, 1901, the Institution was represented by Dr. Leonhard Stejneger, of the National Museum, who reports as follows:

The congress was opened on August 12, and lasted until August 16, when the delegates and members adjourned to attend the reception given in their honor by the High Senate of Hamburg. It was in every respect a success. One of the main factors of this success was the unexampled interest in the congress displayed by the German Government. A large sum of money was placed at the disposition of the com-

mittee by the Government, and the German Crown Prince, as the high protector of the congress, was only prevented from opening the congress in person by the death of his grandmother, the Empress Friedrich, a few days previous. The congress was lavishly entertained by the cities of Berlin and Hamburg, as well as by the Zoological Society of Berlin. But the most extraordinary proof of the public interest in the congress was probably the fact that the entire "Reichstagsgebaüde," the magnificent house of the German Parliament, was placed at its disposition for its meetings, lectures, etc. Thus all the general sessions were held in the great "Plenarsitsungssaal" of the Parliament. The Emperor himself, though prevented from receiving the members officially on account of the death of his mother, took occasion to greet them informally.

The more special object of my joining the congress was to take part in the deliberations and decisions of the committee on zoological nomenclature, of which I had been elected a member at the congress in Cambridge in 1898. The work in this committee on nomenclature was, on the whole, eminently satisfactory from the standpoint of American zoologists, though it was found impossible to lay a draft for a complete code for the congress at its Berlin meeting. It is hoped that this will be accomplished at the next congress which is to be held in Bern, Switzerland, in 1904.

NATIONAL MUSEUM.

The Museum, established in the fundamental act creating the Smithsonian Institution, grew up largely from its private collections, but it is important to consider that now it has grown into something which represents more nearly the large purpose of Congress in its foundation and that it is becoming a "National" Museum. It differs from most other museums in that its primary function was held to be not so much the entertainment or instruction of the resident population as the preservation and arrangement of the collections brought together by the Government of the United States. These collections now outnumber by some millions of specimens those which it has been possible to place upon exhibition in the present utterly inadequate quarters.

I know that the wish of those in immediate charge of the collections is that they may contribute, among other important ends, to establish not only a real educational museum, but one which will interest not only the inhabitants of Washington, but the great numbers of American citizens annually visiting the capital; but this is impossible under the present limitations of space and means. These exhibition features, then, though not the primary purpose of the museum, are for the education and interest of all American citizens, and as accessions come in they require constant change and careful study to bring them to the comprehension of all Americans of all ages and all grades of education.

The definition of an educational museum made by the late Dr. Goode, as "a collection of well-written labels with carefully selected

specimens attached," brings forward the difficulty of the preparation of such a museum, since to compress into a few sentences, in simple yet accurate language, comprehensive and interesting information concerning any specimen presupposes a depth of knowledge and a facility in expression possessed by but few. This task of working upon and improving the educational features of the museum is never ending, and it should be so, for "a perfect museum is a finished museum, and a finished museum is a dead museum."

Collections placed upon exhibition must be constantly renewed, since they deteriorate by the very exposure to the light. The art of taxidermy, methods of installation, the choice of colors for backgrounds, the style and form of labels—all of these details, unnoticed by the casual visitor; matters of constant study to the expert—together form the whole upon which either the pleasant or unpleasant impressions carried away by the visitor depend, but all this is labor lost if they are in situations so crowded as to resemble storage rather than exhibition halls.

Excepting as to improvement in these details, the National Museum, so far as its exhibition halls is concerned, has reached its maximum development in its present quarters. The Secretary has, year after year, continued to call attention to the serious overcrowding of the Museum, and in his report for last year considered the question fully. He is pleased to be able to state that the special appeals made to the last session of Congress by the committee of the Regents resulted in the passage of the following item:

For the preparation, under the direction of the Secretary of the Smithsonian Institution, of preliminary plans for an additional fireproof steel-frame brick and terra cotta building, to cost not exceeding one million five hundred thousand dollars, for the United States National Museum, to be erected when appropriated for, on the Mall, between Ninth and Twelfth streets west, said plans when completed to be transmitted by the Secretary of the Smithsonian Institution to Congress, five thousand dollars.

And it is hoped that the erection of a building may be authorized by the next Congress. This is not the place to discuss the requirements of such a building. In the course of the next session of Congress a detailed statement will be laid before that body indicating the needs, both for exhibition, storage, laboratory, and the numerous other accessories which go to make up a great modern museum. Vast as have been the improvements in the erection of museums in the past twenty years, the ideal standard of building, in which all the requisite features are adequately provided for, has not yet been created in any country in the world. It can hardly be expected that the sum indicated in the above item would be sufficient to supply perfect interior arrangements for exhibition and working purposes, coupled with that

dignity of exterior which has come to be associated with the buildings erected by the Government of the United States.

The Secretary has, however, frequently adverted to the fact that it is not bricks and mortar, nor, even, cases and specimens that make the museum, but (more important than these) the learning and enthusiasm of the men who bring together and classify and describe these collections. Of such men there is an inadequate number, and all are inadequately paid. While wages of laborers and mechanics and the cost of living to all men have advanced by leaps and bounds, the salaries of the scientific staff of the Government, and more especially of the Museum, have to a great extent been kept at a stationary level. The increase in the number of museums, the increase in the number of colleges and universities, the increase in their endowments have all put a premium, as it were, upon the services of men of the first rank, and it is the real devotion of the Museum staff, and not the pecuniary reward which they have received, that has preserved to the Government the services of this distinguished, zealous, and effective, but wholly underpaid body of men.

The best of the scientific staff of the Museum are retained not merely by the unselfishness of their interest in science, but because they can remain there without the duties of tuition, which attach to higher salaries that they can receive in colleges. But they can not be expected to remain indefinitely when so much better terms are being daily held out to them elsewhere.

The Secretary has repeatedly drawn the attention of Congress to the need of the Museum for an increase in the item under "preservation of collections" for the purpose of making at least small advances in the salaries of the staff, and in the estimates submitted this year he has determined to sacrifice needed improvements in many directions with the hope that, on this single item, Congress may see its way clear to approve his recommendation.

To relieve the congestion in some of the most crowded exhibition halls, and to permit the display of a few more of the objects taken from storage, Congress authorized the construction of galleries which have also been found well adapted as temporary laboratories in several departments, and for extension of the Museum library.

The number of specimens received during the year was about 450,000, making the total number of objects nearly five and a half million. The more important additions and general details concerning the several departments are given in an appendix in the report of the Assistant Secretary.

BUREAU OF AMERICAN ETHNOLOGY.

Researches among the native American tribes were continued by the Bureau of American Ethnology, under the supervision of Maj.

J. W. Powell, Director, by means of the usual Congressional appropriation, the formal plan of operations having been approved by the Secretary of the Institution.

The work of the Bureau has related largely to a study of the origin, physical and mental characteristics, arts and industries, food supply, social and political institutions, religions, and languages of these tribes.

A considerable share of attention has been given to distinctly practical questions—relating to the aborigines—to tribal distribution, to subsequent movements and locations of the tribes, to the laws relating to their welfare and their relations to the Government, to treaties, to cessions and recessions of territory.

It has seemed desirable for many years that there should be arranged and published in some methodical form an encyclopedia or dictionary of Indian tribes for which much material has been accumulated, and which it has been intended should present a complete account of them as grouped by linguistic stocks. This is expected to prove of great service to Congress and to public men generally, as well as to institutions of learning, but in view of the time which this great work may be expected to take, the immediate preparation and publication of a dictionary of ready reference to all that is most useful in the past work of the Bureau has been determined upon as the most necessary publication and work of the Bureau in the immediate future.

Field work was conducted by the regular force of the Bureau in Alaska, Arizona, California, and in several other States and Territories, as also in British Columbia, Mexico, Greenland, and in Porto Rico, while useful information and material was obtained from correspondents and special collaborators. Special attention was devoted to a study of those aboriginal industries which appeared to bear practical relations to modern life, particularly to aboriginal methods of house building and irrigation, and to food sources in those tropical and arid regions that formerly sustained a population five to ten times larger than at the present day. A noteworthy investigation of aboriginal industries was conducted in Porto Rico, and a special report of the native resources of that island is in preparation.

A special study was made of a ceremony among the Pawnee Indians embracing songs of interest in the development of music and poetry, and to early phases of the drama, the memoir being accompanied by the primitive music recorded by the aid of the graphophone, and with photographs of movements and objects introduced in the ceremony.

A notable collection of chipped implements, teeth and bones of an extinct elephant, together with a remarkable series of teeth and bones of the mastodon, besides remains of buffalo, deer, horse, and other animals of the historic period, was obtained from a spring in the northeastern Indian Territory. The association of fossil remains with human implements was puzzling until a critical examination by Mr. W. H. Holmes, verified through the memory of an aged Indian chief, indicated

that the spring was a shrine at which aboriginal hunters accumulated votive offerings.

Other researches were carried on and several publications were prepared, as mentioned in detail in the Appendix.

INTERNATIONAL EXCHANGES.

The objects and methods of the International Exchange Service were so fully explained in the Secretary's report for last year that it seems unnecessary to again refer to them further than to say that the service is the medium of exchange of the official publications of the United States Government with the governments of the larger foreign powers of the world, and also the medium of exchange between the principal scientific institutions and libraries of the world.

The maintenance of the American branch of the service is now met in the main by Government appropriations, though the Smithsonian Institution continues to bear a considerable share of the expenses.

During the last fiscal year there was handled an aggregate of 125,796 packages, weighing 396,418 pounds, the packages sent abroad numbering 87,149 and those received from foreign countries 38,647. The various classes of exchanges and other details of the service are explained in detail in the report of the Acting Curator in the Appendix.

It has long seemed desirable to establish more adequate exchange relations with Japan and China, but efforts in that direction have so far been without success. In Great Britain, Germany, and Austria-Hungary it is still necessary to employ salaried agents to carry on the work, the Governments of those countries for various reasons not yet having organized international exchange bureaus.

Congress having made a slight increase in the annual appropriation, it has been possible to considerably improve the service by sending packages by fast express steamers rather than by the slow lines, an advantage much appreciated by all concerned, for in these days of rapid transit on sea and land the literary, scientific, and political world, as well as the business world, is eager to participate in all the advantages of quick transportation.

Five years ago, in 1897, the total number of correspondents or participants in the exchange service was 28,008, while the aggregate has now reached 38,200 addresses of libraries and individuals in 154 countries scattered all over the civilized world, even in some of the remotest corners of India, Asia, Australia, and Polynesia.

The general benefit of the service to the scientific world can hardly be measured. Largely as a result of these international exchanges there has accumulated in the Library of Congress a mass of scientific and Government publications that is probably not surpassed anywhere, and which could scarcely have been secured in any other way.

NATIONAL ZOOLOGICAL PARK.

The importance and interest of the National Zoological Park, under the care of the Regents, is constantly increasing, the total number of visitors for the past year being estimated at nearly a million, the number on single days having several times passed 30,000.

The Secretary has in previous years called the attention of the Regents to the want of a Congressional appropriation for collecting and preserving some of the great land and marine specimens of our Western territory now rapidly approaching extinction, and he again urges the immediate need of doing something, even on the smallest scale, before it is entirely too late. He hopes that Congress may be asked to provide the means to meet these wants by the establishment of at least two small stations or ranches in Alaska, one in the interior, where may be secured specimens of the great moose, the great bear, and other disappearing animals of the land fauna; the other "ranch" to be on the coast for the collection of the walrus, the sea otter, the great sea lion of Steller, and other important vanishing marine species.

The animals in the National Zoological Park at the close of the fiscal year included 506 mammals, 232 birds, and 145 reptiles. The accessions of the year numbered 314. More than half of these accessions were gifts to the Government, several of the most interesting animals having been secured through the cooperation of United States consuls and other officials. A fine specimen of grizzly bear, also some antelope, deer, elk, and cinnamon bears were received from the Yellowstone National Park.

The native game, everywhere plenty when the needs of the park were first submitted to Congress, has grown so nearly inaccessible that only after years of effort have there at last been procured a single young male specimen of the great Kodiak bear and two big horn or Rocky Mountain sheep.

The principal improvements to the park, mentioned in detail in the report of the superintendent on a subsequent page, include the completion of the large flying cage, an addition to the temporary bird house, and an extension or completion of some of the roadways. Work was begun on a new elephant house for which Congress at its last session made an appropriation of $10,000.

Among the present needs of the park, after that for securing native game, are adequate provision for housing tropical mammals, an aquarium, a reptile house, an aviary for small terrestrial birds, and, for the wolves and foxes, which are now in temporary quarters, permanent pens from which they may be unable to escape.

There is no department of the park in which the public takes more interest than in the aquarium, for, notwithstanding the imperfect character of the installation, the tanks being set up in a mere temporary

shed, it is always frequented by visitors. It would undoubtedly be desirable to greatly extend and perfect this collection, so that the public might more completely realize the multifarious living forms that are found in the waters about our coasts, as well as in our rivers and lakes. In order to do this properly a suitable building should be provided and fitted with permanent tanks, heating and refrigerating apparatus, and open pools.

The educational value of an exhibit of this character would unquestionably be very great. Land animals are more commonly seen, and therefore do not excite the wonder that do those creatures that live in an element by which they are most wholly screened from view. The life of the waters is therefore always extremely interesting and surprising.

A zoological collection, viewed in its widest extent, can not be said to be complete while failing to exhibit so large and important a portion of the zoological domain. The biological sciences are becoming more and more studied in our schools, and it is well known that the simpler forms of invertebrates are extremely important as an introduction to the knowledge of higher forms. Classes from the schools of this city and elsewhere often visit the park and find great profit in the aquarium exhibit, even in its present incomplete state. It is hoped that Congress may grant funds for establishing in the park an aquarium on a proper scale.

The park is fulfilling sucessfully the objects for which Congress created it, "The advancement of science and the instruction and recreation of the people." It never has been so successful in these as it is to-day.

THE ASTROPHYSICAL OBSERVATORY.

In appropriating in the sundry civil act, approved March 3, 1901, the sum of $12,000 for the maintenance of the Astrophysical Observatory, under the control of the Smithsonian Institution, during the fiscal year ending June 30, 1902, Congress added the following words:

> That the Secretary of the Smithsonian Institution is directed to report to Congress on the first day of the next regular session an entire account of all appropriations heretofore expended by the Astrophysical Observatory, what results have been reached, and what is the present condition of the work of said Observatory.

In response to this requirement the Secretary submitted a report embracing (1) an entire account of all appropriations heretofore expended by the Astrophysical Observatory, (2) a statement of the results which have been reached, and (3) the present condition of the work of said Observatory, and including as a part of it the first volume of its Annals. This report was accompanied by letters from Sir Robert Ball, Sir William Huggins, Lord Kelvin, Sir Norman Lockyer,

Lord Rayleigh, Sir George Stokes, and other eminent foreign men of science, whose appreciation could not be charged with being influenced by national prejudice, as well as by equally disinterested American ones, all showing a very gratifying approbation of the work of the Observatory by those best competent to judge its merits.

The principal work of the Astrophysical Observatory during the past year has continued to be the study of the sun and its radiation. While fully acknowledging the interesting nature of astrophysical investigation of the stars and nebulæ, the study of the sun has a far superior practical importance, for were the former bodies to be wholly blotted out they would be missed chiefly as objects of scientific interest, while with the sun would be abolished life itself. The solar researches of the past year have mainly been concerned with determining the amount and nature of the absorption of solar radiation in the earth's atmosphere and in the solar envelope. These researches are preliminary to and form an essential part of the measurement of the total radiation of the sun. A presumption exists, almost amounting to certainty, that the total radiation of the sun is variable in some relation to the appearance of sun spots, but nothing is yet known to definitely fix the amount of this supposed variability or to measure its effect upon the earth, though that effect, if so fixed, can not but be of interest to every inhabitant of the earth's surface.

The instrumental means, which thus have been the subject of incessant study and improvement here during the past ten years, for investigating such questions, are more efficient than at any previous time. It will be seen from the detailed report of the aid acting in charge that automatic bolometric curves accurately representative of the amount and distribution of the solar energy at the observer's station may now be obtained in a few minutes, covering nearly the whole spectral region which reaches sea level, and where occurs much of the great and varying absorption by water vapor which influences our terrestrial temperatures so greatly.

Some twenty years ago the writer invented a then new instrument for measuring minute quantities of heat, for, owing to circumstances which this is not the place to detail, an accurate determination of the possible variation in the enormous quantities of heat which the sun sends the earth depends (paradoxically) upon the ability to measure smaller quantities of heat than the most delicate thermometer can possibly do. The "bolometer," the instrument of the writer's invention, which is in question, was able to measure the then unheard of quantity of somewhat more than one one-hundred-thousandth of a degree. Since then, during fifteen years of constant advance, latterly associated with a great improvement of the adjuncts, particularly of the galvonometer, at the hands of Mr. Abbot, this has been brought to measure somewhat less than one one-hundred-millionth of a degree,

and this almost infinitesimal amount is distinguished with readiness and precision. It is this increased precision which is associated with all the improvements in the work of the year here described.

It is the variability of the absorption of our air which now offers the greatest difficulty to the work. The Secretary cherishes the hope that a solar observatory will one day be established high in a clear and dry air, whose chief aim shall be to solve the questions of the amount of radiation of the sun, the changes in this total amount, and the consequences of such changes on the earth.

The interest of this solar study is peculiar among all the subjects of astronomical research, for it is not only a scientific but a utilitarian interest of such high importance that it has among its remote possibilities the forecasting of the coming seasons and harvests, and of conditions immediately practical, from those which affect the price of the laborer's dinner up to those which, to use the weighty words of Professor Newcomb, may bring to light not merely interesting cosmical processes, but "cosmical processes pregnant with the destiny of our race."

In connection with these researches it has proved necessary to obtain a large solar image as free as possible from defects of definition and unequal absorption. One of the most formidable of these defects is that which astronomers call "boiling." This consists of an apparent wavy and rolling motion over the image, and is due to momentary differences of density of the air in the path of the beam. It has hitherto been sought (with little effect) to control this by keeping the air in the tube as still as possible.

I am much interested in a new plan which I have myself proposed, that of thoroughly and incessantly stirring this air column even while the rays forming the telescopic image are passing through it. This experiment of stirring the air has been tried during the past few months at the Observatory, and has resulted in the discovery that by vigorously churning the column of air traversed by the solar beam from a point about 50 feet above the apparatus to the point where the image is formed, the paradoxical result is reached that this image itself becomes nearly tranquil, and that thus the "boiling" can be nearly all eliminated. It is hoped that this very important observation will prove useful to astronomers generally.

For details of the work of the Observatory, including many interesting subjects in addition to those I have mentioned, the reader is referred to the report of the aid acting in charge, which appears in the Appendix.

NECROLOGY.

The Institution has lost by death its presiding officer, ex officio, William McKinley, President of the United States. The life and work of that honored and eminent man and the tragic circumstances of his death are in all minds and they need not be repeated here.

An early Regent of the Institution, the Hon. Matthew Gault Emery died October 12, 1901. From June, 1870, to June, 1871, he was mayor of Washington and a member of the Board of Regents of the Smithsonian Institution as then organized. At the time of his death he was a prominent citizen, particularly in the financial business of the capital city.

Dr. Thomas Wilson, Curator of the Division of Prehistoric Archæology in the National Museum, died May 4, 1902. He had been connected with the Museum for thirteen years and was a most earnest worker. He became widely known by his studies and contributions to the literature of anthropology.

Respectfully submitted.

S. P. LANGLEY,
Secretary of the Smithsonian Institution.

APPENDIX TO THE SECRETARY'S REPORT.

Appendix I.

REPORT ON THE UNITED STATES NATIONAL MUSEUM.

Sir: I have the honor to submit the following report on the condition and operations of the National Museum during the year ending June 30, 1902:

Though having as its primary function the preservation and classification of the Government collections, the National Museum is best known to the public by its educational features, the most obvious of these being the illustration of nature and of the arts of man by means of carefully selected series of objects appropriately labeled and arranged in its exhibition halls in the city of Washington. Its educational work, however, reaches out to all parts of the country through the distribution of its duplicate specimens and the dissemination of knowledge through its publications and by its correspondence. The collections have long since outgrown the accommodations provided for them, and for some years the bulk of the material received has gone into storage. It is, therefore, very gratifying to note the disposition of Congress, manifested at its last session, to grant funds for the erection of a new building.

The accessions during the past year have increased the total number of specimens to above 5,000,000. Besides this, nearly 700 lots of specimens were sent to the Museum from all parts of the country for identification and report, and several thousand letters asking for information on scientific subjects have been received and answered.

There has been a large increase over former years in the amount of duplicate material distributed as gifts to educational establishments and sent out in exchange for an equivalent return, the total number of specimens so disposed of having exceeded 30,000. In addition to the routine duties connected with the care and classification of the collections, much important scientific work has been accomplished by the Museum staff, and the facilities of the Museum for conducting researches have been availed of by many persons not connected with the establishment. Over 6,000 specimens were also lent to specialists for study at their own laboratories.

The number of persons who visited the Museum during the year was 173,888.

Buildings.—The Museum occupies for its various purposes the greater part of the Smithsonian building, the adjacent large brick building, erected about 1880 for its special use, parts of three detached buildings on the Smithsonian and Armory reservations, and several rented buildings south of B street SW. The Smithsonian and Museum buildings are mainly filled with the exhibition collections, but contain also the offices and laboratories and the reference and study collections, so far as it has been possible to accommodate them. The preparators' workrooms and the general storage are mostly outside.

The reports for many years have called attention to the overcrowding in every branch of the Museum. In some of the exhibition halls there are scarcely passageways for visitors between the cases; the reserve series of specimens comprising the

chief scientific wealth of the collections are, to a great extent, barely accessible and their proper arrangement generally impossible; and the laboratories are mostly too small to permit of laying out specimens in course of study or in preparation for display. More serious, however, has been the necessity during many years past of storing very considerable parts of the collections in unsafe buildings, where they are constantly liable to destruction by fire and certain to deteriorate, being buried beyond the possibility of suitable care or inspection. It is therefore pleasing to note that at its last session Congress voted $5,000 for the preparation of preliminary plans for a new building, which when completed should not only relieve this congested condition, but also enable the Museum to develop its educational features and conduct its activities in a manner more creditable to the nation.

Several important alterations and improvements have been made in the Museum building. Some additional space has been gained through the construction of galleries in three ranges—the west-north, the north-west, and the south-west, which are being fitted up for the library and as laboratories for the departments of anthropology and geology.

The steam boilers, which had become entirely worn-out after a service dating from the erection of the building, have been replaced by a pair of high-pressure boilers of modern pattern, with capacity for heating both buildings. The introduction of these made it necessary to overhaul the entire heating plant and to make new and more ample connections with the Smithsonian building. The boilers formerly used in the latter building will be retained in place to guard against emergencies, and the employment of one set instead of two is expected to result in the economy of both fuel and labor.

The installation of a complete system of electric-light wiring and fixtures extending to all the exhibition halls as well as to the offices, laboratories, and storerooms, begun the previous year, was finished satisfactorily. Should it be decided to open the building at night, however, an increased appropriation will be required to cover the cost of extra current and the pay of several additional attendants.

The quarters allotted to the purposes of a lunch room have been somewhat extended and improved, but this very desirable museum adjunct must always remain poorly provided for in the present building.

Organization and staff.—The organization of the museum comprises an administrative office and three scientific departments, as follows: Anthropology, with 8 divisions and 4 sections; Biology, with 9 divisions and 12 sections; and Geology, with 3 divisions and 3 sections.

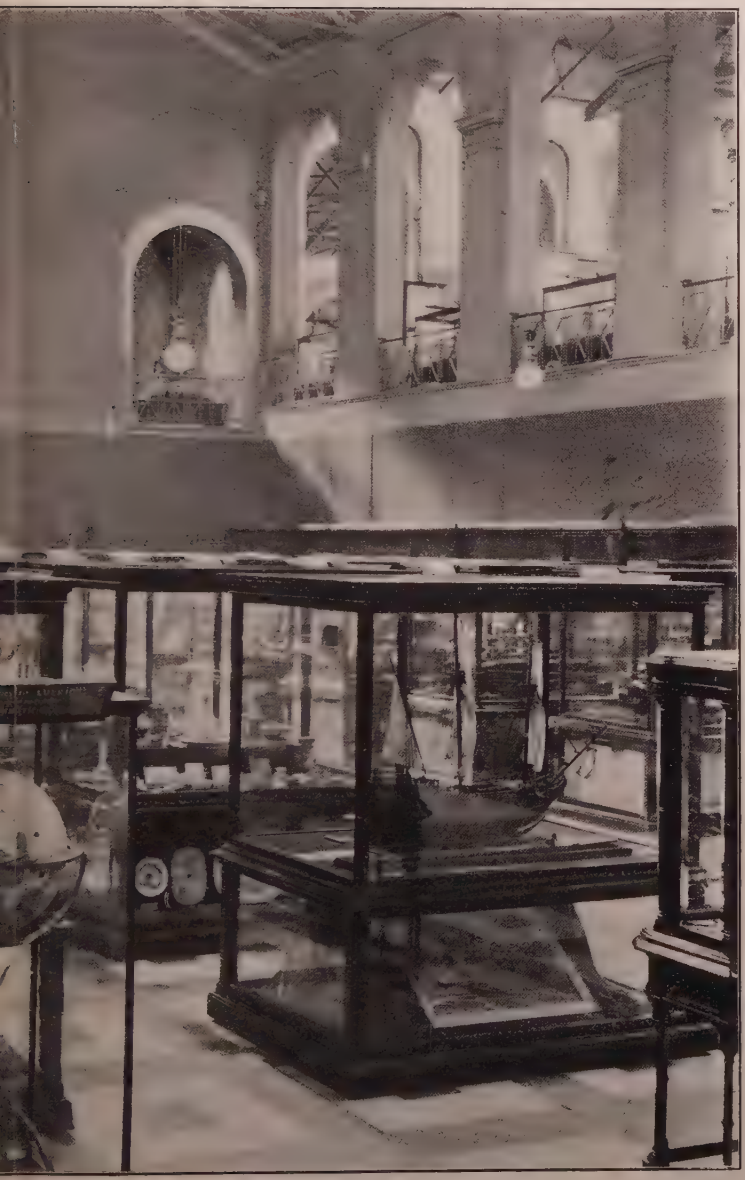
Besides the three head curators in charge of the departments, the scientific staff at the close of the year consisted of 17 curators, 12 assistant curators, 14 custodians, 11 aids, 4 associates, and 2 collaborators, making a total of 63 persons, of whom, however, only about one-half received compensation from the Museum. Of the remainder, who are serving in a volunteer or honorary capacity, the majority were attached to other scientific bureaus of the Government.

The death of Dr. Thomas Wilson, which occurred on May 4, 1902, deprived the Museum of one of its most earnest and helpful workers. Widely distinguished for his studies and contributions on a variety of anthropological subjects, Dr. Wilson's interests lay chiefly in the field of prehistoric archæology, and from 1889 he had charge of the extensive and important collections of this division of the Museum.

Mr. William V. Cox, who was appointed to the Museum in 1879, and has been its chief clerk since 1886, with important duties in connection with all the recent expositions in which the Government has participated, severed his official relations with the Museum in February, 1902, greatly to the regret of his associates, to accept a more responsible position elsewhere. The duties of this office have been somewhat modified to better consolidate the administrative work, and the title of its chief

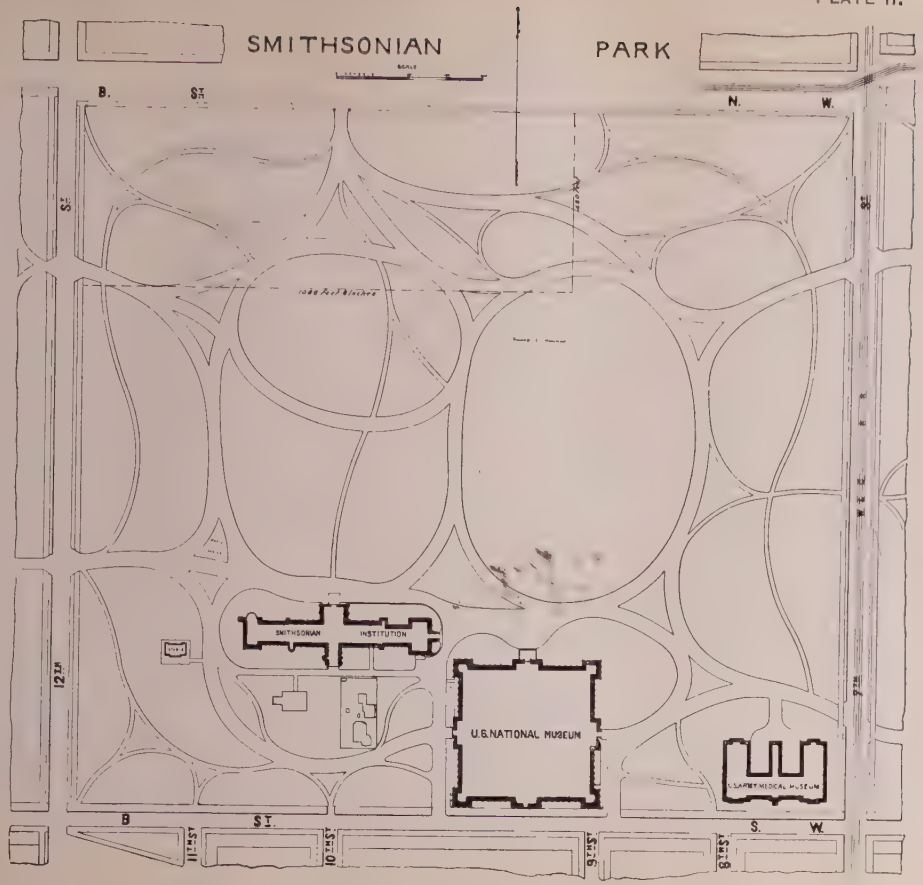


HALL OF AMERICAN HISTORY IN NATIONAL M



SHOWING CROWDED CONDITION OF EXHIBITION HALLS.

PLATE II.



PLAN OF SMITHSONIAN PARK.

Dotted line incloses approximate location of proposed new building for National Museum.

officer has been changed to administrative assistant. This position was filled by the appointment of Mr. W. de C. Ravenel, previously the assistant in charge of fish culture in the United States Fish Commission, who has joined to a long experience in the administrative work of that Bureau a familiarity with the preparation and installation of Government exhibits.

Mr. George B. Turner has been made chief taxidermist and Mr. W. C. Phalen an aid in the Department of Geology.

Additions to the collections.—The collections of the Museum were increased during the year to the extent of over 448,000 specimens, bringing the total number of specimens in its possession up to more than 5,400,000. The additions were received in 1,409 separate lots or accessions.

Among the important contributions in the Department of Anthropology were a quantity of baskets, weapons, ornaments, and parts of costumes collected by Dr. W. L. Abbott in the Andaman and Nicobar islands, and many objects, including crania, native clothing, lamps, and articles connected with the industries of the Eskimo, obtained in northern Greenland and Ellesmere Land by Mr. Robert Stein, of the United States Geological Survey, during his Arctic expedition. A number of Guatemalan costumes and of objects illustrating the first steps in the weaving of cotton as practiced in that country, as well as other ethnological material, were received from Mrs. Mary W. Owen, of Panzos, Guatemala. Two interesting donations were a series of weapons captured during the Philippine insurrection, including several Filipino swords of the ordinary type, some bolos, and a kris, from Maj. E. L. Hawks, U. S. Volunteers; and a collection consisting principally of the different types of punal de kris, a weapon carried by the women and children in the Philippine Islands, together with a device formerly used in the Philippine army for decapitating wounded soldiers, from Dr. W. C. Warmsley, of Norwich, Conn. Another Philippine collection, secured by purchase from Mr. J. N. Harkins, of Calhoun, Ga., comprises weapons, cooking utensils, tobacco boxes, charm belts, models of boats, newspapers, statuettes, and coins.

A collection of choice objects brought together by the late Dr. G. Brown Goode, and secured during the year, in ludes musical instruments, Japanese porcelains, domestic utensils, gambling devices, plaques, vases, an incense box, old Kutani ware, Marcusi ware, Cloisonné plates and bowls, trays, English chinaware, and ironstone china from China. Other additions to the collection of musical instruments were a small series of instruments used by the American Indians, and several from European countries, including a nyckleharpa, obtained by exchange from Mrs. J. Crosby Brown, of Orange, N. J.; and 78 pieces, comprising instruments of the Javanese, Chinese, Thibetans, Japanese and Persians; Syrian and Egyptian kettledrums, a Turkish mandolin, etc., presented by Dr. Ryan Devereaux, U. S. Army.

A complete set of the gold and silver coins of Siam, and a series of Spanish coins minted in Mexico and the Philippine Islands, embracing the various kinds issued by Spain for use in its colonies, were obtained by purchase.

Loan collections, chiefly of historical interest, received on deposit and exhibited in the main Museum hall, were as follows: Eighty-two relics of Colonial times, and a gold watch worn by George Fayette Washington, a nephew of George Washington, from the National Society of Colonial Dames; relics of the Revolutionary War, including commissions in the Continental Army, from the Daughters of the American Revolution; several swords that had belonged to the late Rear Admiral J. W. Philip, U. S. Navy, one presented by the children of Texas, another by the citizens of New York City, from Mrs. Philip; six swords belonging to Rear Admiral R. D. Evans, U. S. Navy, including one presented by the State of Iowa, and one by the crew of the battle ship *Iowa;* and 21 guns captured at Tientsin, China, comprising the various types of European and American manufacture now employed in the Chinese army,

from Col. W. H. Carter, U. S. Army. A desk and quadrant used by Dr. C. F. Hall, on his *Polaris* Arctic Expedition, were received as a gift from Miss Anne S. Hall, of Cincinnati, Ohio.

Among the important accessions in archæology were the collection of flint implements, bone utensils, and remains of extinct and recent mammals resulting from the examination of a sulphur spring at Afton, Ind. T., by Mr. W. H. Holmes, and a very large amount of material, comprising pottery, implements of stone, wood and shell, bones and human remains, obtained by Dr. Walter Hough during his investigations in Arizona, partly in conjunction with Mr. Peter G. Gates.

About 10,000 prehistoric objects from Georgia, including carvings, spearheads, polished stone hatchets, and other articles of stone, ivory, and pottery, were acquired from Dr. Roland B. Steiner. A collection of the implements used by the ancient inhabitants of Columbia County, Pa., consisting of stone articles of domestic utility, stone hatchets, banner stones, arrow points, and spearheads, was presented by Mr. Charles Hummel, of Espey, Pa., and a large series of prehistoric objects from the Potomac Valley was obtained by purchase.

Among the accessions in archæology from other countries were over 600 specimens of prehistoric vases, stone figures, carvings and polished instruments, and figures and dishes in earthenware from Mexico, received from Mr. E. O. Matthews; material from the guano caves of Las Cruces, New Mexico, contributed by Mr. J. R. De Mier; an image, mortar and pestle of stone, from Porto Rico, presented by Mr. Henry Bird, and a series of flint implements and bones from the cavern of Kesserlock, Schaffhausen, Switzerland, donated by Prof. J. Heierli, of the University of Zurich.

The additions to the technological collections include several of historical value, such as pieces of apparatus devised and used by Dr. Elisha Gray in his experiments with harmonic multiple telegraphy and with the telephone, received from Mrs. Gray; one of the tin-foil records made by Edison's first phonograph when exhibited before the National Academy of Sciences at the Smithsonian Institution in 1878, contributed by Mr. William J. Rhees; a number of electric lighting and telephone devices, and one of the early forms of typewriting machines.

In the Department of Biology the collections sent by Dr. W. L. Abbott from the East Indies, consisting principally of mammals, birds, reptiles, and insects, formed the most important zoological accessions. Of mammals there were 848 specimens, including many new species, from the islands of Andaman, Nicobar, Linga, Sinkep, Johore, and others farther eastward; of birds, over 700 specimens, and of reptiles, a considerable number. The region visited by Dr. Abbott is in large part a new field, not previously represented in the National Museum, and the generous contributions from this indefatigable explorer give the Museum a collection from this region which is absolutely unrivaled.

Other specimens of mammals received, deserving of mention, were a fine skeleton of the huge Kod'ak (Alaska) bear, from Mr. J. H. Kidder, of Boston; African antelopes and monkeys from Dr. A. Donaldson Smith, of Philadelphia; many skulls of moose, elk, and other deer from Mr. Ernest Thompson-Seton of New York; and a large series of small mammals from Germany and of squirrels from Asia.

Among ornithological material were about 300 Cuban and Porto Rican birds, collected by Mr. B. S. Bowdish; a quantity of Cuban birds collected by Mr. William Palmer; a series of East Indian birds from the Royal Museum of Natural History at Leiden, Holland; a large number of Brazilian birds from the Museu Paulista at São Paulo, Brazil; besides smaller collections from Mexico, Cocos Island, Hawaii, and Great Britain. Several rare species of birds' eggs were obtained.

The reptilian collection was enriched by the field work in Cuba and Porto Rico of Mr. B. S. Bowdish and Mr. William Palmer. Specimens were also received from Japan, Sumatra, and the Philippine Islands.

The Division of Fishes was fortunate in securing, through Messrs. Anderson and Price, of Ormond, Fla., the skin of a whale shark (*Rhinodon*), 13 feet long, the first of its kind recorded as being taken in the North Atlantic Ocean. The Leland Stanford Junior University presented the types of a large number of Japanese fishes described by Dr. David S. Jordan, and also specimens from Panama, Cocos Island, and the Galapagos Islands. A collection of Egyptian fishes from the Nile was contributed by Dr. Bashford Dean, of Columbia University, and interesting material from several sources was transmitted by the United States Fish Commission.

Twelve species of land shells from Cocos Island, cotypes of species described in E. von Marten's work on the mollusks of that locality, were donated by Mr. William H. Dall. Some 2,000 shells from Lower California were received from Lieut. C. A. Clarke, U. S. Navy, and a number of new species of North American land shells from Mr. J. H. Ferris, of Joliet, Ill.

The largest addition to the Division of Insects comprised about 65,000 specimens collected by Mr. E. A. Schwarz, custodian of the coleoptera in the Museum, in Arizona, at his own expense, and by him presented to the national collections. The Museum was already indebted to this generous friend for the gift of his extensive private collection previously formed. Some 7,000 insects of several groups were brought from the Hawaiian Islands by Mr. W. H. Ashmead, and 10,000 specimens of lepidoptera from Colorado by Dr. H. G. Dyar, assisted by Mr. A. N. Caudell. The expeditions on which this material was secured are referred to elsewhere. Ten thousand beautifully prepared specimens of butterflies, mainly from Mexico and Central America, have been deposited in the Museum by Mr. William Schaus, of Twickenham, England.

The Division of Marine Invertebrates received from the United States Fish Commission a series of Porto Rican sponges, identified by Dr. H. V. Wilson, of the University of North Carolina; echini and holothurians from the same locality, identified by Prof. H. L. Clark, of Olivet College; the crustaceans and echinoderms collected during the expedition of 1901 to the Hawaiian Islands; and a quantity of material from the marine station at Woods Hole, Mass. The extensive collection of corals made some years ago at the Philippine Islands by Prof. J. B. Steere and Prof. Dean C. Worcester was obtained by purchase. Among the smaller accessions of importance were a quantity of marine invertebrates from Ellesmere Land, collected by Mr. Robert Stein; a series of the cave crustaceans of Kentucky and Tennessee from Prof. W. P. Hay; a number of Alaskan crustaceans from Mr. R. S. McGregor, of the U. S. Coast Survey steamer *Pathfinder;* and samples of the Atlantic sea-bottom from the United States Navy.

Through the generous bequest of Dr. Charles Mohr, of Asheville, N. C., who died in July, 1901, the Division of Plants became possessed of his entire collection of flowering plants, comprising more than 18,000 specimens, chiefly from the southern United States. Two years previously Dr. Mohr had presented to the Museum his collection of about 3,000 specimens of cryptogamic plants from the same region. From his trip to Central America during the summer of 1901 Mr. J. N. Rose brought back a large number of plants, including specimens from Mount Orizaba and Mount Popocatepetl, and also some living plants, which were deposited in the greenhouse of the Department of Agriculture. A valuable collection from China and the Philippine Islands was contributed by the Royal Botanic Gardens of Kew, England; over 6,000 plants from various parts of the United States and from Brazil, Guatemala, Mexico, and Porto Rico were transmitted by the Department of Agriculture; and about 4,200 Chinese plants were acquired by purchase.

In the Department of Geology the accessions have been numerous, and in some of its divisions of more than ordinary importance. Among the rocks and ores transmitted by the United States Geological Survey were many specimens illustrative of

its recent explorations in Colorado, Montana, and Oregon. A large quantity of ore samples from the United States exhibit at the Paris Exposition of 1900 was turned over to the Museum by the Government Board. The minerals added to the collection comprise many varieties, a number of which were not previously represented. Especially worthy of mention are a fine specimen of native tellurium from Delamar, Nev.; a magnificent mass of moss gold on quartz from the "Miner's Dream" mine, Old Chester district, California; characteristic samples of Alaskan gold; fine specimens of molybdenite from Okanogan County, Wash.; axinite from Switzerland and Japan; beautiful crystals of tourmaline from Mesa Grande, Cal.; and zeolites from Golden, Colo. Following are the new species obtained: Narsarsukite, percylite, yttrocerite, picroallumogene, bornite (in crystals), espistolite, plumboferrite, ankylite, sulvanite, thalenite, elpidite, and lossenite. Fine specimens of tourmaline and amethyst were received as a gift from Dr. L. T. Chamberlain, honorary custodian of gems and precious stones.

The meteorite collection was increased during the year to the extent of 29 falls, and now comprises specimens representing a total of 356 distinct falls. The most valuable addition was a stony iron meteorite from Admire, Kans. The sources of other important specimens were as follows: Misshof, Courland, Russia; Rafrüti, Switzerland; Cereseti, Piedmont, Italy; St. Mesmin, Salles, and Lacon, France; São Julião de Moreira, Portugal; Limerick, Ireland; Shalka, Bengal, India; Rhine Villa, South Australia; Weston, Conn.; Algoma, Wis.; Monroe, N. C.; Tombigbee, Ala.; Tonganoxie and Kiowa County, Kans.; and San Angelo and Kendall County, Tex.

In invertebrate paleontology there were several very large and important additions. Some 15,000 specimens, including 10,000 brachiopods, 4,200 bryozoans, many cretaceous forms from New Jersey, and cystids and crinoids from Maryland, composing the private collection of Mr. Charles Schuchert, assistant curator of stratigraphic paleontology, were donated by him to the Museum. Prof. George M. Perdew also presented his entire collection of Silurian and Devonian fossils, about 1,300 specimens, from Cumberland, Md. The E. O. Ulrich collection of Ostracoda, containing about 5,000 specimens, and the type and figured specimens of 100 species, was acquired by purchase. The transmissions from the Geological Survey included 3,755 specimens of Cambrian brachiopods, which had been the subject of special study by the Director, Dr. Charles D. Walcott.

The extensive series of teeth of the elephant and mastodon, obtained by Mr. W. H. Holmes at Afton, Ind. T., associated with prehistoric implements, has proved of great interest, several species being represented.

The accessions in Paleobotany include a valuable collection of fossil plants, comprising the type specimens described by Prof. Ebenezer Emmons in his American Geology, part 6, 1857; 100 specimens from the auriferous gravels of California, collected by Mr. C. D. Voy; 40 specimens from what may be the Upper Jurassic formation in the vicinity of the Corwin coal mine, near Cape Lisbourne, Alaska; about 300 specimens from the Miocene Lake beds of the South Fork of John Day River, in Grant County, Oreg., transmitted by the Geological Survey; and about 100 specimens of Upper Carboniferous plants from the vicinity of Plympton, Mo., described by Mr. David White in the Fossil Flora of the Coal Measures of Missouri, and presented by Dr. John H. Britts, of Plympton.

Explorations.—Owing to the very limited means available for field researches, the amount of work of this character carried on by assistants of the Museum has been relatively small, and most of the expeditions made were only rendered possible through cooperation with other bureaus of the Government or through the generosity of individuals. The Government explorations by which the Museum is most benefited are those conducted by the Geological Survey, the Fish Commission, the Department of Agriculture, and the Bureau of Ethnology of the Smithsonian Insti-

tution. Officers of the Army and Navy, with the exceptional opportunities now afforded them, have also been doing some excellent work for the Museum, especially in the Philippine Islands. In this connection mention should likewise be made of the important explorations which Dr. W. L. Abbott, of Philadelphia, has been carrying on for several years in the East Indies entirely at his own expense, the results being generously donated to this Institution. The latter comprise large collections in zoology and ethnology, whose value is enhanced by the fact of their coming from a region hitherto scarcely represented in any museum in the world. The field work engaged in during the year by members of the Museum staff was as follows:

Mr. W. H. Holmes, head curator of anthropology, visited Indian Territory and Missouri, in the former investigating an interesting deposit of flint implements and bone utensils associated with the remains of extinct and recent mammals at Afton, and an ancient chert quarry on the Peoria Indian Reservation, and in the latter examining near Kimmswick an extensive deposit of fossil mammals in which human remains were said to occur, and an ancient village site containing stone implements and pottery. The investigations begun by Dr. Walter Hough in Arizona, in June, 1901, were continued through the summer, in conjunction with Mr. Peter G. Gates, of Pasadena, Cal., and chiefly at the expense of the latter. An archæological section was made on a north and south line from Fort Apache to Moki, a distance of about 180 miles, and a large amount of material was obtained. Ethnographical work was also done among the Apache, Navajo, and Hopi Indians, and two new groups of ruins north of Holbrook were mapped.

Mr. W. H. Ashmead, who accompanied an expedition of the United States Fish Commission to the Hawaiian Islands in May, 1901, for the purpose of making collections of insects and of studying the insect fauna of these new possessions, returned late in the summer with an important lot of material. Mr. B. S. Bowdish, formerly of the United States Army in Porto Rico, was employed for about seven months in procuring zoological specimens, chiefly birds, in Porto Rico, in eastern Cuba, and on Mona Island. Mr. C. L. Pollard and Mr. William Palmer accompanied Dr. Edward Palmer, of the Department of Agriculture, in the spring of 1902 on an expedition to eastern Cuba, where they obtained an interesting collection of plants, birds, bats, insects, and marine invertebrates.

The station of the Cabot Steam Whaling Company, on the south coast of Newfoundland, was visited during the summer of 1901 by Dr. Frederick W. True, who made a special study of the sulphur-bottom whales, obtained many photographs, and arranged for the preparation and shipment to Washington of the skeleton of a large whale. In a collecting trip to Colorado, Dr. H. G. Dyar, in company with Mr. A. N. Caudell, of the Department of Agriculture, secured some 10,000 specimens of Lepidoptera, and Mr. E. A. Schwarz made in Arizona, at his own expense, a very large collection of insects. Two months, during the spring of 1902, were spent in southern Illinois by Mr. Robert Ridgway, in the interest of the Division of Birds. Botanical explorations were carried on in Central America during the summer of 1901 by Mr. J. N. Rose, assisted by Mr. Robert Hay, of Washington.

Important collections were made by Mr. Charles Schuchert of Helderbergian fossils in New York and of Cretaceous fossils in New Jersey. Mr. F. W. Crosby obtained for the Museum a remarkably fine series of pot holes from the basalt rocks near Snake River Falls, Idaho.

Exchanges.—The use of its duplicate specimens in effecting exchanges with other scientific establishments and with individuals was recognized by the act founding the Institution as an important means of increasing the collections of the Smithsonian Museum, and so it has proved to be during the more than fifty years that the practice has been followed. The amount of material involved in each transaction ranges from one or a few specimens to collections of considerable size, while the equivalent

obtained generally consists of species or objects not previously represented. The duplicate specimens have therefore a high value as a purchasing medium, and have been, as a whole, the principal resource of the Museum for filling gaps in the collections, and for completing its series along many lines. Much valuable material was secured through this means during the past year from both domestic and foreign sources, the institutions and individuals abroad entering into exchange relations having been as follows:

Great Britain: The British Museum of Natural History at London, the Royal Botanic Gardens at Kew, Mr. E. Lovett, of Croydon; Prof. A. C. Haddon, of Cambridge; Messrs. Sowerby and Fulton, of Kew; Mr. H. Sidebottom, of West Stockport, Cheshire, and the Rev. F. W. Galpin, of Harlow. France: The Museum of Natural History at Paris; Mr. Georges Lachenand, of Limoges; Prof. Michel Gandoger, of Arnas (Rhone); Mr. Réné Martin, of Le Blanc (Indre), and Prof. S. E. Lassimonne, of Moulins, Allier. Germany: The Senckenbergisches Museum at Frankfort-on-Main; Dr. J. Thiele, Mr. L. Frobenius, and Mr. C. Schirmer, of Berlin; Dr. Edward Rosenstock, of Gotha, Thuringen, and Dr. E. Schellwien, of Konigsberg. Austria: The Imperial Royal Natural History Museum at Vienna. Italy: The Royal Zoological Museum at Florence; Prof. M. Bezzi, of Sondrio; Dr. Felippo Sylvestri, of Bevagna, Umbria, and Mr. Luigi Gardinale, of Vicenza. Switzerland: Mr. E. von Fellenberg, of Berne, and Mr. M. Micheli, of Romilly, Geneva. Portugal: Prof. Paul Choffat, of Lisbon. Holland: The Rijks Museum of Natural History at Leiden and Mr. M. Buysman, of Middleburg. Belgium: Mr. Victor Mahillon, of Brussels. Sweden: The Zoological Institute of the University of Upsala, and Mr. Sven Ekman, of Upsala. Japan: The Imperial University at Tokyo. India: The Royal Botanical Garden at Seebpore, near Calcutta. South Africa: The Albany Museum at Grahamstown, and the Botan cal Gardens at Berea, Durban. Brazil: The Museu Paulista, São Paulo. Chile: The National School of Mines. Uruguay: Señor Serveriano de Olea, of Montevideo. Mexico: The National Museum at the City of Mexico. Jamaica: Jamaica Botanical Gardens at Kingston. Canada: The Geological Survey of Canada at Ottawa, and Mr. James Fowler, of Kingston.

The exhibition halls.—The crowded state of most of the exhibition halls has prevented extensive additions to the display collections except in a few directions. Much work was done, however, toward improving the condition and appearance of these collections by small additions, and by the substitution in many instances of better material and of a higher class of preparations. Considerable progress was also made toward completing the system of labeling. It had been anticipated that provision would have to be made during the year for housing the Museum exhibit at the Pan-American Exposition. A large part of the material was, however, sent to the South Carolina Interstate and West Indian Exposition, but before the close of the year the entire collection was back in Washington. The objects returned directly from Buffalo have been mainly cared for by the transfer to storage of some of the less desirable preparations previously displayed, and by utilizing, though only temporarily, a part of the lecture hall.

In the Department of Anthropology several of the halls have been thoroughly renovated, in some the collections have been reinstalled, and space has been found for a few new ethnological groups.

Among the additions in the Department of Biology were many finely mounted specimens of American mammals and birds, a part of the display at the Pan-American Exposition, the former including a large specimen of Steller's sea-lion and a skeleton of the Kadiak bear. In the south-east Museum range, allotted to reptiles, batrachians, and fishes, some improvements have been made, several new cases being provided, many new preparations replacing older ones, and a number of large forms not previously represented being added. Among the latter were a cast of the King Cobra snake with accessories representing the edge of an Indian jungle, a very large

Amazon River turtle, a Mata-mata turtle, a huge alligator snapper, the largest of the North American water turtles, several boas, lizards, toads, and frogs. An exhibit of lizards will be arranged in some of the wall cases.

The permanent installation of insects in the hall recently assigned to this group at the western end of the Smithsonian building has progressed to the extent of mounting about 2,700 specimens in 20 of the standard boxes occupying several upright cases. In the labeling of this series attention has especially been called to species of peculiar habits and to those of most interest to the public.

To the display of vertebrate fossils have been added partial skeletons of the large *Triceratops prorsus* and of the carnivorous dinosaur, *Allosaurus*. The installation of the Harris collection of invertebrate fossils, in a section of the rail case of the gallery in the southeast court, has been practically completed. This collection, received in 1898, is one of the finest yet made in the region it represents, being especially rich in crinoids, star-fishes, and trilobites, containing of the last group about 600 out of the 750 species known from the Cincinnati formation.

The collections relating to physical and chemical geology have, in part, been thoroughly overhauled and rearranged, and about 100 photographs, maps, and other pictures illustrative of these subjects have been placed on the adjoining walls. The building of galleries in the south-west range made it necessary to remove for a time the collection of minerals, which, at the close of the year, was being reinstalled after careful renovation.

Publications.—The publications issued during the year comprised volume 23 of the Proceedings, and a number of papers belonging to volume 24, Part I of Bulletin No. 50, Bulletin No. 51, two additional parts of Bulletin No. 39, and Circular No. 51, descriptive of the collections illustrating rock weathering and soil formation, recently prepared for distribution to educational establishments. While the annual report for 1900 in complete form was not received from the Government Printing Office until after the close of the fiscal year, a small edition of the several papers composing it was distributed as separates at an earlier date.

Bulletin No. 50, entitled "The Birds of North and Middle America," by Mr. Robert Ridgway, is intended to contain descriptions of all the species and subspecies of birds known to occur on the North American continent, and will consist of several parts or volumes. Part 1 treats of the Fringillidæ; part 2, covering the Tanagridæ, Icteridæ, Cœrebidæ, and the Mniotiltidæ, is in press. Bulletin No. 51, compiled by Mr. R. I. Geare, is a list of the publications of the National Museum from 1875 to 1900, including all papers printed in the Reports and Proceedings, and has an index by titles. The additions to Bulletin No. 39 are, a revised edition of Mr. Gerritt S. Miller's "Directions for collecting and preserving study specimens of small mammals," with abstracts in German, French, and Spanish, and "Directions for collectors of American basketry," by Prof. O. T. Mason.

Library.—The additions to the library during the year numbered 613 books, 13,065 pamphlets, and 5,885 parts of periodicals.

Expositions.—At the Pan-American Exposition held in Buffalo, N. Y., from May 1 to November 1, 1901, the Museum, in conjunction with the parent institution and its other branches, made an extensive and exceedingly creditable display. The main features consisted of a large number of life-sized lay-figure groups illustrating the type tribes of American aborigines, of finely mounted specimens of many of the larger American mammals, birds, reptiles, and fishes, and of the skeletons and restorations of several of the large fossil vertebrates of the western United States.

Upon the close of this exposition, in accordance with the directions of the President of the United States, a carefully selected collection from the above exhibit was transferred to the South Carolina Interstate and West Indian Exposition, which opened at Charleston on December 1, 1901, and continued until May 31, 1902.

For the Louisiana Purchase Exposition, to be held at St. Louis, Mo., during the summer of 1904, Congress has appropriated $450,000 toward the erection of a Government building and $800,000 for the preparation and installation of an exhibit by the several departments and bureaus of the Government. Dr. Frederick W. True, head curator of biology, has been designated to represent the Institution and Museum on the government board of management, having served in the same capacity in connection with the Pan-American and Charleston expositions.

Respectfully submitted.

RICHARD RATHBUN,
Assistant Secretary.

Mr. S. P. LANGLEY,
Secretary of the Smithsonian Institution.
AUGUST 1, 1902.

Appendix II.

REPORT OF THE BUREAU OF AMERICAN ETHNOLOGY.

Sir: I have the honor to report on the operations conducted in the Bureau of American Ethnology during the fiscal year ending June 30, 1902, under authority of the act of Congress making provision "for continuing researches relating to the American Indians under the direction of the Smithsonian Institution," approved March 4, 1901. The work was carried forward in accordance with the formal plan of operations submitted on May 20, 1901, and approved by the Secretary on May 23, 1901.

Field operations were conducted in Alaska, Arizona, British Columbia, California, Colorado, Chihuahua (Mexico), Greenland, Indian Territory, Iowa, Maine, Missouri, New Mexico, New York, Oklahoma, Oregon, Porto Rico, Texas, and Wyoming. The office work covered material gathered from most of the States and Territories, as well as from various other parts of the American hemisphere.

Scope of the Work.

The researches of the year were conducted in accordance with an ethnic system set forth in the earlier reports. This system may be defined as the Science of Ethnology in its modern aspects. Although based on investigations in all parts of the world during the past century, the system is essentially the product of the researches in American ethnology during the last two decades of the nineteenth century. Now that the system has assumed definite form, it affords a foundation not only for future researches, but for applying the principles of ethnology to practical questions. Accordingly the work of the year was gradually turned toward lines bearing directly on questions of public interest.

Among the lines of work in what may be called Applied Ethnology, to which special attention has been given during the year, two may be particularly mentioned:

1. *Physical ethnology.*—On the institution of the Bureau in 1879 the Director found the science incomplete in that it dealt largely with merely casual characteristics of tribes and races, and neglected the essential characteristics expressed in the activities, or the doings, of peoples. So, special attention was given to the habitual doings of the several tribes studied, and at the outset each was regarded as an activital type or genus; these were then compared, and in the light of the comparison the activities themselves were analyzed and afterward grouped systematically. It was in this way that the science of demonomy, with its subdivisions each relating to a group of activities, was developed. Now this great science, dealing as it does with the doings of tribes and races, each regarded as a typical group, is practically confined to the artificial or psychical side of mankind; it barely touches the natural or physical attributes; yet it affords a basis for classifying these attributes and measuring the influence of the prime force of demotic activity in shaping their development. In other words, the earlier ethnology dealt only with features and traits inherited from prehistoric ancestry; what may be called the New Ethnology deals with those traits and human powers by which mankind is distinguished from all other organisms. The researches indicate that such traits and powers, such features and faculties, are connected with the normal development of tribes and races, and are, indeed, the essential factors in the growth of nations. Accordingly it would seem that the time

is at hand for applying the principles of the New Ethnology to American aborigines as ethnic constituents of a growing citizenship. The application requires a statistical study of physical characteristics, including viability, industrial aptitude, etc., of typical Indian tribes, together with a similar study of mixed bloods, or mestizos, both conducted with a view of comparison with Caucasian and other ethnic norms. The importance of this line of inquiry is suggested by the fact that there are no physical statistics on record of any tribe of our passing race available for comparing stature, strength, endurance, viability, fecundity, and other physical attributes, with those of Caucasians, either with the view of gratifying our instinctive desire for knowledge or with the object of deriving useful information from the experience of other peoples. The importance of inquiries concerning mestizos is sufficiently indicated by the history of a neighboring Republic, whose president is at once a product of the blended blood of the white and red races, and one of the foremost among the world's national leaders. Singularly, there are no trustworthy records of mestizos in this country, though their number must reach some 30 to 60 per cent of that of the pure-blood Indian population. Nor is it to be forgotten that many of the practical problems connected with immigration, Chinese exclusion, the occupation of Porto Rico, Hawaii, and the Philippines, and the education of the colored race can be finally solved only in the light of ethnologic principles, whether these be developed through slow experience or derived from scientific researches already advanced to the applicable stage. These and other weighty considerations have led to the inauguration of researches in physical ethnology. During the fiscal year a series of physical records made by Dr. Franz Boas among the Siouan Indians, with photographs representing the physical types, was accepted for publication.

2. *Aboriginal economics.*—It is well known that aboriginal America gave the world corn, the potato, certain beans and squashes, tobacco, two varieties of cotton, and the domestic turkey; it is not so well known that the native tribes utilized various other natural resources which might well be introduced into the dietary and commerce of Caucasian peoples; and still less is it realized that various prepared foods in habitual use by the Amerinds are of unsurpassed excellence—for while succotash and hominy have come into general use, the far superior pinole, tamale, and pemmican are only locally used by whites and many other desirable dishes are entirely neglected. When the Bureau was instituted it was a common impression that the aborigines were mere huntsmen and fishermen, whose habits were in the highest degree vicious and improvident; but as the human activities were defined and the aboriginal industries were adopted it became more and more evident that many of the tribes were essentially agricultural, and that all subsisted in much larger degree than commonly supposed on the produce of the soil. As researches progressed the importance of various aboriginal food sources neglected by the Anglo-Saxon became clear, and at the same time it became clear that our people might learn much from the red man concerning the simpler agricultural methods and the ways of bringing plants and animals under cultivation and domestication. The success of the native in utilizing natural resources is well illustrated in the arid region comprising that portion of the country still unsettled. The traveler over the principal railway from a few miles west of El Paso to a few miles east of San Bernardino traverses a zone supporting a Caucasian population of some 20,000, with perhaps half as many Indians; the same zone abounds in ruins of aboriginal dwellings, temples, acequias, and reservoirs, attesting a population fully ten times greater during the agricultural period antedating the Apache wars of the last eight or ten centuries. It is highly significant that our least-populated arid districts in the Southwest are those yielding most abundant evidences of numerous population during prehistoric times. A specific example may be found in Arivaca Valley, Arizona, with a present population of less than 100; yet one of seven prehistoric villages within the valley comprises ruins of more than 120 dwellings, with temple, corral, stadium, and plazas, evidently representing a population

of fully 600 for the village and 3,000 to 5,000 for the valley. Although the depopulation began in the prehistoric age, through wars still in progress at the time of discovery, the historic period has witnessed a part of the change; for it can not be doubted that Cabeza de Vaca, Coronado, Alarcon, and their followers saw within the zone between western Texas and eastern California a population twice or thrice the aggregate now subsisting within it, and this despite modern multiplication of industries connected with mining, grazing, and transportation. The success of the aboriginal husbandman in this region was partly due to a system of irrigation so satisfactory that modern farmers often profit by the prehistoric ditches; yet his chief advantages grew out of a more economical adjustment between labor and produce, including crops now neglected. Among the neglected crop plants are various cacti (locally known as saguaro, pitahaya, nopal, saguesa, etc.), whose fruits sufficed to support the entire native population for some two months of each year, though they are never used by Anglo-Saxon settlers. These cacti are products of the desert par excellence, adjusted to their habitat during geologic ages, and, in some way not yet made out, deriving their vital energy chiefly from light; and they give promise that (unless exterminated by vandalism) they will some day yield to intelligent cultivation and add an invaluable resource to our arid districts. The researches concerning aboriginal food sources have been coupled with other studies in native economics, including those pertaining to textiles used for clothing, birch bark used for canoes and habitations, the making of baskets, etc. In most cases the immediate aim was to record the primitive customs and crafts as a contribution to knowledge of a passing race, but the investigations have reached the stage of yielding useful lessons to the superior race. As announced in recent reports, productive studies of the beginning of agriculture and zooculture have been conducted. During the past fiscal year a memoir on Wild Rice, by Dr. Jenks, has been published, with a view of directing attention to a natural resource giving promise of value to modern agriculture; Dr. Russell spent the greater part of the year in a critical study of a typical tribe of the arid region (the Pima Indians), and has prepared a memoir on their industries for early publication; a systematic investigation of the birch-bark industries of the aborigines was taken up by Dr. Jenks; and Dr. Fewkes devoted a part of the year to a special study of the aboriginal economy of Porto Rico, with particular reference to the artifacts and customs still extant, and giving promise of future value to that newly acquired territory.

Except for the diversion of a portion of the energies of a few collaborators to the applications of ethnology, the work has been continued along former lines; and, as heretofore, most of the collaborators have been employed partly in the field and partly in the office.

The organization of the work, which is slightly modified by the applications herein set forth, may be defined as follows: (1) Physical characteristics (including the demography of the native tribes), or somatology; (2) mental characteristics, or psychology; (3) arts (including games, sports, etc.), or esthetology; (4) industries (including economics), or technology; (5) laws, or sociology; (6) languages, or philology; and (7) myths (together with attendant ceremonies and other observances), or sophiology. Customary attention has been given also to general and classific work, to the illustration, editing, and publication of reports, to distribution of the published material, and to the ancillary office work.

Field Research and Exploration.

The Director spent over three months in Maine, engaged (so far as impaired health permitted) in researches among the northeastern Algonquian Indians and in revising his classificatory writings designed for the guidance of operations in the Bureau. The linguistic and other material obtained from the Indians was utilized directly in

the more general work, including the linguistic classification described in other paragraphs.

Although occupied chiefly in adminstrative work, the Ethnologist in Charge made a reconnaisance in eastern-central Colorado early in the fiscal year, visiting certain archæologic localities, notably in the vicinity of Pueblo, Colo., and tracing the conditions affecting tribal movements during prehistoric times about the borderland between the peoples of the plains and those of the mountains and plateaus.

On August 16, Dr. J. Walter Fewkes proceeded to southern Colorado and northern New Mexico for the purpose of extending archæologic explorations in districts hitherto inadequately studied. His operations were extended southeastward through New Mexico into western Texas and northern Chihuahua (Mexico); in the latter State he made the most critical study thus far attempted of the extensive prehistoric ruins known as Las Casas Grandes. Throughout, he made extended notes on the surviving tribes, as well as on the various types of ruins and other relics, of which a carefully selected collection was brought in on his return to the office on November 20.

On April 28 Dr. Fewkes sailed for Porto Rico, with the object of making such a reconnaissance of this and neighboring islands as might serve to throw light on those aboriginal industries still surviving and giving promise of utility, and at the same time form a basis for a more extended investigation during the current year. Although scarcely extended beyond Porto Rico, his work was successful, yielding material for a special report. He returned to Washington and began the preparation of this report just before the close of the fiscal year.

Mr. James Mooney proceeded, on September 17, to the field in Oklahoma and Indian Territory, where he resumed a special investigation of the heraldic systems employed among the Kiowa, Kiowa-Apache, and Cheyenne tribes. His work continued throughout the fiscal year, yielding the greater part of the material required for an exhaustive monograph on one of the most interesting customs of the American aborigines. In connection with the study of the devices, a considerable objective collection was brought together for preservation in the National Museum.

Throughout the entire fiscal year Dr. Frank Russell was in the field, chiefly in Arizona, though his operations extended into New Mexico and Colorado, and about the close of the year into the Muskwaki habitat in Iowa. During the earlier months he made an extended archæologic reconnaissance of the upper Gila Valley, pushing his journey southward to the international boundary, westward to the area already covered by other collaborators, and northward to the border of the plateau country; thence the surveys were extended over the plateaus into Colorado and New Mexico for the purpose of comparing the lowland antiquities with those of the highlands. During winter and spring he located in the Pima country, near Sacaton, and began a systematic study of the industrial and other customs of the Pima tribe. The work yielded material for a special report on the technology of the tribe and for a more general monograph on the historic and prehistoric inhabitants of the Gila Valley.

On October 30 Dr. Albert S. Gatschet repaired to Indian Territory for the purpose of completing his Peoria vocabulary and grammar, and making cognate researches among the few survivors of the Peoria tribe. He was able to perfect his records of the language of the tribe during the ensuing month and bring his work to a successful close about the middle of December.

The beginning of the year found Dr. John R. Swanton engaged in researches concerning the language and social organization of the Haida Indians in British Columbia. This work continued until September, yielding voluminous material for publication in future reports. On September 30 he returned to Washington and began preparing the material for printing.

Under the immediate guidance of Dr. Franz Boas, philologist, Mr. H. H. St. Clair, 2d, spent the first three months of the year in linguistic researches in Wyoming

and Oregon. In the former State he made a full record of the local Shoshoni dialect, and in the latter he made a partial collection of the lexic and grammatic material of the Wasko and Piute languages. Under similar guidance, Mr. William Jones made a critical study of the Muskwaki language in Iowa and Indian Territory; and Dr. Roland B. Dixon recorded the languages of the Maidu and other tribes of northeastern California under the auspices of the American Museum of Natural History, but with an arrangement (noted elsewhere) by which the material is available in the Bureau work.

On September 25 Prof. W. H. Holmes, of the National Museum, and Mr. De Lancey Gill, of the Bureau, repaired, under the auspices of the Bureau, to northeastern Indian Territory for the purpose of examining a spring reported by a correspondent to contain abundant bone and flint implements associated with bones of both modern and extinct animals. They were successful in obtaining (1) the finest collection of mammoth teeth thus far made in America; (2) one of the finest collections of mastodon teeth ever made, and (3) the most striking collection of chipped arrow points, lance heads, and knives thus far made in a single locality in this country. They verified the reported association and were able to identify the spot as an aboriginal shrine to which the attention of the aborigines was probably directed by the gigantic teeth and bones of extinct animals, and at which sacrifices were made through several generations. During the same trip they visited Kimmswick, Mo., where also human relics are reported to occur in association with bones of extinct animals. Toward the close of the year Professor Holmes again visited this locality, and, with the assistance of Mr. Gerard Fowke, made a considerable collection for preservation in the Museum.

In November Dr. Robert Stein returned from a two years' absence in Ellesmereland and northern Greenland, where, under facilities afforded by the Bureau, he obtained ethnologic data of interest relating to the northern Eskimo, or "Arctic Highlanders." Besides a small objective collection designed for preservation in the Museum, he brought in the words and music of several songs which serve to establish the existence of an archaic language among these people, and at the same time to demonstrate for the first time, and despite a prevailing opinion to the contrary, the existence of a fiducial cult among them.

Under a special arrangement, Miss Alice C. Fletcher visited Oklahoma early in the fiscal year for the purpose of verifying and extending her records of certain Pawnee rituals designed for publication by the Bureau. Later she employed certain aged Pawnee Indians to recite the ancient rituals in such manner as to permit the making of phonographic and other records. Her efforts have resulted in unique contributions to knowledge of the esoteric customs connected with human sacrifice and other rites in pre-Columbian times and still surviving in emblematic form. A part of the material has been incorporated in a monograph on the Hako ritual, forming part of the Twenty-second Annual Report. Also under a special arrangement, Dr. Willis E. Everette sent in useful records concerning the Athapascan tribes of Alaska.

During the earlier part of the year Mr. O. P. Phillips was employed temporarily in making motion pictures representing the industries, amusements, and ceremonies of the Pueblo and other tribes in New Mexico and Arizona. The object of the work was to obtain absolutely trustworthy records of aboriginal activities for the use of future students as well as for the verification of current notes on fiducial dances and other ceremonies. Despite accidents to the apparatus, the work was fairly successful, yielding about a dozen kinetoscope ribbons in addition to about a hundred excellent photographs made by Mr. Phillips in connection with the motion pictures. The apparatus was kindly furnished in the interests of science by the Armat Moving Picture Company, of Washington.

Office Research.

work in somatology.

During the later months of the year definite steps were taken toward systematic record and investigation of the physical characteristics of the aborigines. A nucleus was already available in the form of an extended anthropometric record made by Dr. Franz Boas among the Siouan Indians several years ago and acquired by the Bureau in 1899; and it was decided to prepare the matter for early publication, partly as a record of the physical characteristics of a typical group, partly as a model for future work. In order to enhance the value of the publication it was arranged to have Dr. Boas prepare an introduction treating of somatology in general terms and to have Mr. De Lancey Gill, the illustrator of the Bureau, prepare suitable illustrative material from the photographic negatives preserved in the office. The memoir is well advanced, but was not quite completed at the close of the year.

For some years past photography has been employed in the Bureau in such a manner as to yield useful anthropometric data. Thus, in dealing with the wilder tribes, who would resist ordinary physical measurements on fiducial or other grounds, the collaborators have made it a point to obtain group photographs with the figures so placed as to permit measurement of stature and other physical elements in terms of a known unit figure introduced for the purpose; and, similarly, visiting Indians photographed in the Bureau laboratory have usually been so placed with respect to backgrounds and other objects as to permit physical measurements of sufficient accuracy for practical purposes. During the past year special attention has been given to photographing individuals in exact portrait, profile, and full face, with the view of permitting the extension of measurement to the facial angle, form of cranium, and other anthropometric elements. This was done not only in the office, but to some extent in the field, especially by Dr. Frank Russell, who made a large number of profile and full-face photographs of Pima Indians. Although the system is not yet perfected, it gives promise of excellent results as the reasearches in somatology progress.

Various collaborators of the Bureau have collected crania and other somatic material in connection with their field operations. For some years the material was preserved in the United States Army Medical Museum, but it has now been transferred to the United States National Museum, where the current collections of the collaborators are now regularly sent. In the absence of specialists in somatology in the Bureau, portions of the somatic material have been placed during the last year or two in the hands of experts not connected with either Bureau or Museum, for special investigation; and it is a pleasure to acknowledge the service rendered to the Bureau in this way by Dr. George A. Dorsey, of Field Columbian Museum, and Dr. Ales Hrdlicka, of the American Museum of Natural History. A provisional arrangement has been made for having such work done within the Bureau hereafter.

work in psychology.

For some years past the Director has given special attention to the mental characteristics of the aborigines; and during recent months he has formulated a working system of psychology adapted to the needs of ethnologic students. In part, the results are embodied in a series of synthetic outlines of ethnologic science designed for incorporation in successive reports and printed in somewhat abbreviated preliminary form in a leading journal (the American Anthropologist) for the purpose of eliciting suggestions from contemporary ethnologists in this and other countries. An abstract of the principles underlying this series, designed for incorporation in the present report, was printed in December, 1901, under the title "Classification of the sciences."

In addition to his duties as Ethnologist in Charge, Mr. W J McGee continued the application of the principles of psychology to the current researches. Two methods

of psychologic inquiry have been successfully pursued in the past. While these are in some degree antithetic, they also measurably represent stages in the development of knowledge. The first method may be defined as that of introspection; the second as that of experiment. During the past decade the latter has attained great vogue, and departments of experimental psychology have been built up in several universities and colleges. The two methods, more especially the latter, afford a foundation for a third method, which is alone available for the study of large groups, such as races, nations, or entire peoples. It may be defined as the method of direct observation of normal interactions. In pursuing this method it is assumed, on the basis of experimental psychology, that physical acts are correlated with mental actions—in other words, that human thought and human action are interdependent. The recognition of this simple principle removes the need for a large part of the detail work involved in experimental psychology, for it permits the interpretation of mental characteristics of individuals and groups from their habitual or normal actions rather than from a repetition of special actions in a prearranged series. For this reason it has not hitherto been deemed necessary to introduce psychometric work in connection with the ethnologic researches, the observations on Indian habits and artifacts seeming to afford a satisfactory index to and measure of the aboriginal mind. In its general aspect the principle may be said to have been established early in the history of the Bureau through observations on activital coincidences, which have since been formulated in the comprehensive law of the Responsivity of Mind; so generalized, the principle may be regarded as the keynote of ethnic science, the Rosetta stone whereby the characters of all races may be interpreted. The recognition of the principle serves also to explain and establish the sequence of stages in human development inferred from observations on many peoples (i. e., from savagery, through barbarism and civilization, up to enlightenment), since it shows that each transition was the product of cumulative experiences, long assimilated and applied through commonplace habits rather than through abstract reflection—for in all the lower stages of human progress the mind borrows from the hand. Customarily the stages of culture are defined on the basis of social organization, but they may be defined nearly as conveniently in terms of psychic development. So defined, primordial savagery is not merely the stage in which the law rests on maternal kinship, but that of instinctive imitation, in which experience is perceptive rather than apperceptive, while knowledge increases through accident rather than design. Similarly, barbarism is not only the stage of paternal kinship and patriarchy, but that of awakening apperception accompanied by distrust and dread of nature, in which knowledge is stimulated by notions of divination, with accompanying physical tests slowly assimilated in conscious experience. In like manner civilization is not simply the stage of law based on territorial right, but that of habitual discovery, in which new-found facts are consciously perceived and utilized. So, also, enlightenment means more than mere recognition of individual rights as the basis of law; for it is the stage of invention and of the union of individuals for conquest over nature through the exercise of definite prevision based on accumulated experience. Defined in a word, respectively, the four psychic stages are those of (1) imitation, (2) divination, (3) discovery, and (4) invention. Now, among the applications of the principle of the interdependence of thought and action, none are more important than those pertaining to the developmental stages; for the leading problems of the world to-day are connected with the lifting of lower races and more primitive cultures to the planes of civilization and enlightenment. The special applications are innumerable, but they cluster about the general facts (1) that in primitive culture thought is engendered by action, (2) that in higher culture thought leads action and (3) that hence the most effective ways of raising lower peoples are those of manual rather than mental training. All systematic observations indicate that

in the earlier stages the mental clings to the manual so closely that the primitive artisan feels the implement as a part of himself and commonly believes that a part of his personality goes out into both tool and product; thus his craft is a constant stimulus to mental activity and prepares him for further steps in the long way leading from the plane of fettering instinct to that of free invention. When the savage or barbarian is so far educated that his hand intuitively moves knife or saw or plane by pushing outward instead of pulling inward, his mind is in the third quarter of the normal course of development; but to this position he can be raised only by the oft-repeated example and simple precept of rational training applied to lower races. The researches along these lines are not complete; some of the results were incorporated in a brief paper on "Primitive numbers," published in the Nineteenth Annual Report; and a preliminary account of certain results was issued during the year under the title "Germe d'une Industrie de la Pierre en Amerique."

WORK IN ESTHETOLOGY.

Although Mr. Mooney remained in the field throughout the greater part of the year, his researches were such as to yield material for a prospective report on Indian heraldry. His investigations during several years past have shown that various Indian tribes possess heraldic systems analogous in many ways to those of mediæval Europe, and that such a system is especially developed in the Kiowa tribe; and his work during the year was carried forward in this and neighboring tribes. The ways in which the system is developed render the study extremely difficult. The principal heraldic devices are closely akin to totems, and are of two types, one pertaining to tipis and the other to shields. The tipis, with their devices, belong to families or clans in which they are hereditary. The shields, with their emblematic (or armorial) bearings, belong to typical aboriginal groups or brotherhoods, which arise in connection with the bearings themselves. Usually the devices are "dreamed" by a shaman (or, as he conceives it, revealed to him in a vision), the dream indicating also the number of shields that it is permissible to make with the particular bearing of the revelation. In due time the shields are made in accordance with the shaman's dream, and these are adopted by unattached warriors as special devices or crests until all are in use. Each shield usually bears two devices, one on an outer covering of skin placed over the shield proper, which may be regarded as a symbol of the bearing within, and the other or real device on the face of the shield beneath the cover. The latter is never revealed save in sacred ceremony and in battle, when it is displayed as a magical device for offense, as well as defense, against enemies. Each of the shields is eventually regarded by its bearer, or keeper, as the symbol of his special tutelary and a sort of receptacle for his personal spirit of warfare. It is prized and kept sacred during his lifetime (the purpose of the cover being to protect the sacred device from sacrilegious gaze), and, unless sacrificed in his declining days on the death of a kinsman, is buried with his body—he enters on the dark under-world path of his faith with his head pillowed on the device which mysteriously carried him safely through many dangers in all the days of his life. By reason of the habitual sacrifice of shields and the decline of aboriginal customs, few now remain, though fortunately many others are preserved in memory and tradition. Moreover, the devices can be adequately studied only with the aid of their respective keepers and bearers who can be induced to reveal the magic, or "medicine," of the devices, or—still better—to reconstruct them in such manner as to permit the investigator to trace the interrelated meanings of the various features as they are slowly wrought in accordance with archaic ritual. The family tipis have also become rare, though nearly every family has surviving representatives acquainted with the family crests and with the ritualistic and other modes of constructing both tipis and heraldic devices. Mr. Mooney's method has been to employ survivors of both brotherhoods and families to reconstruct their shields and tipis, respectively,

with all the armorial bearings of the olden time, the objects to be preserved in the National Museum after the study is finished. Naturally the task has been a tedious one; yet the progress has been satisfactory. The heraldic systems of the native tribes are of much interest in that they open the way to knowledge of various obscure customs of primitive peoples and also to vital stages in cultural progress. Thus, the devices represent a peculiar development of totemism; they are closely related with the calendric systems found among the tribes of the plains; and through these they are akin to the glyphic systems employed in the aboriginal books and sculptures of Mexico and Central America. Moreover, since they represent the transition from prescriptorial to scriptorial culture, they are found to throw much light on the genesis of those European systems of heraldry whose origin is lost in the darkness of the prehistoric. Finally, the heraldry of those tribes in which it is best developed forms a nucleus for the esthetic activities generally; in them artistic shapement and coloring find their highest expression; in connection with them the powers of imagination and the inspiration of fiducial symbolism attain their highest perfection, and through them ritual and faith and the intensely dramatic ceremonial warfare were crystallized and kept alive. To the lowly aborigines they were more than the text and picture and drama of higher culture. The greater part of the material for a monograph on the subject was brought together during the year.

Ethnologists have long realized that the widest gateway to aboriginal life is that afforded by games of chance; for primitive men, especially in that barbaric culture in which divination is the keynote of psychic character, are habitual gamesters, and not only devote much time to gaming, but play openly and with such infatuation as to afford constant opportunities to the student. The lowly games of the native Australians, New Zealanders, and Polynesians have received much attention; those of Korea, Japan, and China, in which the barbaric element of divination is supplemented by skill, have been described by eminent authors; the games of the American aborigines have been studied not only by collaborators of the Bureau, but by other able ethnologists, notably Tylor; and the various studies afford a foundation for systematic research. The work was taken up incidentally by the late Frank Hamilton Cushing, with the collaboration of Dr. Stewart Culin, of Philadelphia, author of notable treatises on Korean and other games. The joint study was incomplete at the time of Mr. Cushing's death; subsequently it was carried forward independently by Dr. Culin. During the year an arrangement was effected with Dr. Culin under which he has nearly completed a monograph on Amerind games for publication by the Bureau. In the prosecution of the work he has made several field trips, has examined material in all the leading museums of the country, and has prepared numerous photographic and other illustrations. The results of the study are of much interest in that they illustrate a curious commingling of the fiducial and fortuitous in the notions of primitive gamesters. Actually the games are played as of chance rather than skill (though considerable skill is eventually developed); yet the playing is essentially devotional toward the mysterious potencies held to control the physical world and govern human affairs. Accordingly the games played for pastime run curiously into the most sacred ceremonies, and the devices employed afford a fruitful revelation of primitive thought. By reason of the wealth of material, the monograph has become voluminous. It was not quite ready for delivery at the end of the year, but is promised for the first quarter of the current year.

During the year Prof. W. H. Holmes, now of the United States National Museum, completed the monograph on aboriginal pottery of Eastern United States, of which he prepared the first draft while an officer of the Bureau. Although primarily technologic, it forms an important addition to knowledge of aboriginal esthetics. As repeatedly noted in the ethnologic work, esthetic motives invariably arise in symbolism and develop through a conventionism shaped by ancillary or adventitious conditions, including texture of materials, character of tools, etc., as well as

growing conceptuality and power of imagination. Now, no line of esthetic development is more complete than that represented in the decoration of fictile ware, and the author of this monograph, combining as he does thorough technical knowledge of the potter's craft with high artistic skill and unique esthetic feeling, has been able to trace in masterly fashion and to illustrate effectively the growth of fictile decoration. As a faithful description of aboriginal pottery, the treatise will undoubtedly become a classic; yet it is no less noteworthy as the most comprehensive contribution thus far made to the history of one of the most important activities in those stages of culture in which the shapement and decoration of pottery have ranked high among the avocations of mankind. The monograph forms the body of the Twentieth Annual Report.

During the year the series of graphic representations of personages in the Hopi pantheon collected by Dr. Fewkes, as mentioned in previous reports, was sent to press as a part of the Twenty-first Annual, under the title "Hopi Katcinas." Dr. Fewkes also completed the illustrated memoir on his unique collections of pottery and other material from Arizona and New Mexico noted in the last report. It is in press under the title "Two summers' work in Pueblo ruins," as a part of the Twenty-second Annual.

WORK IN TECHNOLOGY.

Primarily Professor Holmes's monograph on aboriginal pottery of Eastern United States is a description of the fictile ware classified by districts, so far as practicable by tribes, and also by technologic types. The art of the potter is old, far older than written history, so that its beginnings can never be traced directly. The antique and prehistoric wares themselves yield a partial record of the development of the art, and the archæologists of the Old World have been able to supplement and extend the written history of pottery making through study of such material, and their researches have lent interest to the ancient vessels and sherds with which the museums of the world are enriched. Yet the fictile ware of Egypt and Babylonia, Etruria and India, and other Old World provinces falls far short of telling the whole story of the art, since it fails to reveal the actual motives and sentiments of the early artisans—the relics are husks of the history of pottery making without the vital kernel. Accordingly the archæologic studies in America supplement the European researches in a highly useful way. In the first place, the period of pottery making by the American aborigines was comparatively short, so that the prehistoric and the historic are closely related; and, in the second place, the several living tribes within reach of current observation represent various stages in the development of the art, so that opportunities exist in America for studying the motives and sentiments of the artisans engaged in all of the earlier developmental stages of the art. In general, the craft of the potter may be said to arise in the social stage of savagery or the psychic stage of imitation, with its tedious growth through accidental improvement; in general, too, the art may be said to expand and differentiate in the succeeding barbaric stage with the attendant divinatory concepts as motives; and it is this stage, with its protean forms, textures, decorative devices, and modes of manufacture, which has been found peculiarly inscrutable by students of the products alone. Now, it is precisely this stage which is represented by most of the American aboriginal ware, both prehistoric and historic, and by the surviving tribes. Accordingly Professor Holmes's description of the American ware, with his critical analysis of types and interpretation of motives, would seem to afford not merely a supplement to, but a sound foundation for, the history of the potter's art. The monograph, which forms the body of the Twentieth Annual Report, embraces faithful representations of some 250 typical specimens.

Of the two special investigations concerning aboriginal industries undertaken during the year, that by Dr. Fewkes in Porto Rico would seem to be of the more general interest. While his trip to the Antilles was designed as a reconnoissance of Porto





PRIMITIVE PORTO RICAN HABITATIONS.

Rico, Haiti, and the islands immediately adjacent, he was prevented, partly by the volcanic disturbances of early May, from extending observations beyond the first-named island; yet this failure of plan resulted beneficially rather than otherwise, since it enabled him to make a more definite ethnologic and archæologic survey of Porto Rico than was at first contemplated. Among the surviving types of aboriginal handicraft to which he gave special attention were those connected with habitations. In all parts of the American hemisphere the prevailing house type is in some measure a composite, or blend, of the indigenous and the imported; and while in most districts the imported motives are so far predominant that the indigenous elements are hardly traceable, there are other districts, especially in tropical, subtropical, and arid regions, in which the aboriginal types are of such excellence that many elements have been retained with advantage by Caucasian settlers. This is especially true in the Antilles, where natural conditions of climate, water, and available material have led to light and inexpensive types of construction by which European settlers have been glad to profit. The types are somewhat analogous to those which have been better developed in the Orient, especially in Japan, and which are frequently commended to the attention of occidental builders and householders. When it is remembered that the prevailing Anglo-Saxon types are at once adapted to the rigorous climate of northwestern Europe and adaptations of materials developed in the northern temperate zone, it becomes evident that they are not well suited to our southern temperate zone, and especially to our tropical and subtropical possessions. Then, when it is remembered that the indigenous types, e. g., of Porto Rico, are specifically adapted to the local climate and adaptations of local materials, it would seem clear that architectural motives derived from them ought to be even more useful than any borrowed from Japan. These considerations have influenced the researches in Porto Rico, and they are in part the motive of the special report on Porto Rico prepared by Dr. Fewkes. Other motives have grown out of the native food sources which have been found useful by generations of European settlers, and out of those aboriginal modes of food preparation which are of such excellence as still to survive. It would appear from the observations that several native foods are worthy of attention and cultivation by settlers from the United States, and that some of the indigenous modes of preparing food might well receive careful study with a view to maintaining the excellence of the preparations when more advanced modes of handling, milling, preserving, and transporting are introduced. The details of Dr. Fewkes's investigations are incorporated in a memoir designated for early publication in the form of a bulletin. The industrial data are supplemented by bibliographic and other material, which will render the report a manual of Porto Rican ethnology and archæology.

The special investigation undertaken by Dr. Russell among the Pima Indians covered aboriginal industries developed in and adapted to the arid region. Here, as in Porto Rico, local types of habitation have resulted from the climatic and other local conditions. The primal house type is a small circular structure of canes or reeds, roofed with earth, the whole supported by an inner framework of poles. This type is differentiated according to available materials, the grass house and the house of cactus (okatilla stems or saguaro ribs) being closely related derivative forms. It is differentiated also by arrangement of material, as when the canes or cactus staves are wattled with reeds or withes, and the house tends to become square in plan with vertical walls eventually beplastered by the washing of mud from the roof and by the throwing up of embankments as wind-breaks below. Under the imitative instinct of savagery the wattled walls are coated with a mortar of mud, which is magically "hardened" by the embedment of pebbles and larger stones; and this may be deemed the secondary type of aboriginal architecture in southwestern United States and northern Mexico. From it develops under favorable conditions a third type—i. e., that of rubble masonry set in mortar of mud or even laid dry; but where building stone is lacking, the pebble-set wattle structure grows into a distinctive

architecture of which the basis is the puddled wall, or pisé, called by Spanish settlers "cajon," the fourth house type of the arid region. Aboriginally, the earth used in the structure was doubtless tamped between wattled walls, at first permanent and afterwards temporary; certainly during later times the earth was built up in successive ledges between movable screens of wattling so placed and braced as to form a temporary trough for each ledge. The cajon structure was durable, and was susceptible of development into communal houses of many rooms and several stories. As in the primal type, the roof remained of earth laid on shrubbery supported by a sheathing of canes or cactus staves and rafters of cedar poles; on one-story houses it was a place of temporary resort for the occupants, and with the gradual evolution of parapets and the growth of these into higher stories the roofs became upper floors. Subsequently (probably after the Caucasian invasion) earthen bricks laid in mud mortar were substituted, and this type of construction, known as adobe, was generally adopted; and in the better buildings, both of cajon and adobe, the walls were coated with a thin plaster or slip fixed by some form of soda or other earthy salt. Now, the aboriginal cajon house type is admirably adapted to the present needs of the arid region and is well worthy of consideration by Caucasian settlers. Properly constructed, cajon walls are much superior to adobe in homogeneity and strength, though somewhat more expensive in labor. Their durability is sufficiently attested by Casa Grande in the Gila Valley, which was a ruin of immemorial antiquity when discovered by Padre Kino in 1694, and which is still standing despite vandalism as well as natural weathering. Moreover, the cajon is readily susceptible of improvement by the addition of lime or cement to the material in any desired quantity and by substituting a plaster of lime or cement for the simple slip. So improved, the native construction would seem better adapted to the conditions and requirements of habitations in the arid region than any imported models. The cost would be only that of the lime and the handling of materials, while wood, burned brick, and even stone are highly expensive. The thick walls would effectively equalize interior temperatures despite the enormous diurnal range, which is the most serious obstacle to residence in arid districts; and the general massiveness would lend itself to distinctive and desirable architectural effects. Dr. Russell's researches extended also to the lighter and more composite types of construction surviving among the Pima and neighboring Indians, as well as to the attendant industries and food sources. Among the latter the fruit of the cactus figures prominently, not only in modern customs but in tradition and ceremonies, attesting the still more important place which the fruit and its products occupied in the lives of past generations. Dr. Russell's material has been so divided as to yield a special memoir on technology, designed for early publication in bulletin form, and a general monograph on the social organization, mythology, and esthetology of the Pima tribe and on the antiquities of their habitat.

During the year Dr. Albert E. Jenks revised the proofs of his memoir on "Wild rice gatherers of the upper lakes," forming part of the Nineteenth Annual Report. This treatise is deemed especially valuable in that it calls attention to a widespread food source largely used by the aborigines and giving promise of great utility to our citizens whenever the requisite attention is given to cultivation, milling, and preparation. In food value the wild rice ranks high among cereals, and its natural habitat is such that by its means otherwise useless swamp lands may be utilized and reclaimed, while it can not be doubted that with judicious cultivation it might be adapted to an ever-widening range of soil conditions. Later in the year Dr. Jenks resumed his researches concerning the birch-bark industries of our northern aborigines. As noted in the last report, one aspect of the industries clustering about the birch tree is of prime significance to ethnologists in that the birch-bark canoe was the most effective agency of distribution of tribes and culture during early times; yet it is well worth noting that the interest is a living one, since the bark canoe remains a most effective device for transportation among white men as well as red.

Indeed, its use by white tourists, fishermen, hunters, etc., is apparently increasing in northern United States and Canada. Various other birch-bark artifacts are in use among whites as well as natives. The half conventional, half symbolic makok, or maple-sugar box, proves to form a convenient household utensil; birch-bark baskets of different forms are found useful as well as artistic; and on the whole it would appear that the birch-bark industry is not only increasing in consequence of demands by whites, but that it serves as a helpful stepping-stone from the primitive customs of the Indian toward the free and self-supporting citizenship which is the Indian's ultimate goal. Exigencies connected with the editorial work of the office compelled Dr. Jenks to divert a part of his time from the research. Accordingly, the work was not quite completed at the end of the fiscal year, when Dr. Jenks was, at the request of the Director of the Philippine Bureau of Nonchristian Tribes, furloughed for a year, with a view to the more effective introduction of the methods of the Bureau of American Ethnology in the Philippine researches.

For several years Mr. J. D. McGuire has been engaged in investigating certain lines of aboriginal technology, and certain of his results have been published in the reports of the United States National Museum. During the last fiscal year he began, at the instance of the Director, a critical study of the earliest records of aboriginal technology made by the Conquistadores, missionaries, and other pioneers. During the year just closed he continued the work and has made a series of extracts from the records which have proved of great use to the Director and the collaborators engaged in field researches. The extracts are arranged on cards, and certain installments of these have been acquired for the use of the Bureau.

WORK IN SOCIOLOGY.

Throughout most of the year the time of the Ethnologist in Charge has been so fully occupied with administrative work, largely relating to publication of the reports, as to somewhat delay his sociologic inquiries; yet fair progress has been made. One of the special inquiries of the year relates to what may be called, by extension of common terms, aboriginal land tenure, this investigation being rendered timely by current progress in the allotment of lands in severalty to former tribesmen, as well as by recent occupancy of territory formerly inhabited by native tribes in Alaska, Hawaii, and the Philippines. The researches indicate that primitive peoples have no conception of land tenure in the sense in which the terms are employed by civilized and enlightened peoples. In the first place, there is no recognition of individual title to lands or other natural values, for any such values are regarded as pertaining to the clan, the gens, or the tribe, i. e., possession is communal rather than individual. In the second place, the property sense is especially inchoate as applied to lands, which are viewed as natural ranges for men and animals, i. e., for local tribes and local fauna; and there is no recognition of ownership or title inimical to the natural and coordinate rights of other men and beasts. True, there is among most tribes a vague sense of prescriptive right to long occupied territory, i. e., to the home of the ancients who play so prominent a rôle in primitive philosophy, so that commonly a tribe feels it a right and a filial duty to protect the home range against permanent invasion by aliens; yet the vague right so recognized scarcely applies to the land per se, but only to the rights of the chase, fisheries, fruits, and any cultivated products, personal habitations, quarries or clay pits, etc., i. e., to what may be called the usufruct of the soil. In other words, the attitude of the savage or barbarian toward property in land is much like that of American citizens during the last century toward property in water, i. e., in the rains, rivers, lakes, seas, artesian water, ordinary ground water, et al., during recent decades the idea of property in water has grown up in the less humid districts and is rapidly extending, yet the development of the concept is slow, even in the minds of the most intelligent people. Perhaps a closer parallel may be found

in air as viewed by enlightened peoples, for the air is regarded as essentially common to all living and breathing things, and its use as an inherent right far transcending conventional titles to personal or communal property. There are, indeed, certain germs of communal property right in air, manifested in the occasional actions of neighborhoods looking to the abatement of certain nuisances, yet the claims put forth in such actions relate rather to the free and common use—or to usufruct—of the air than to its possession as property, so that our attitude toward air is closely analogous to that of primitive folk toward land. The results of the inquiries find ready application in connection with various public questions. One of the conclusions is that primitive folk can not be at once transferred from the plane of collective interest in the usufruct of the soil to that of individual land tenure, any more than the farmer of the Atlantic seaboard could be brought in a day to full understanding of irrigation water rights, with all the complications of dams, sluices, main ditches, gates, etc.—indeed, the education of the citizen farmers who have gone West and grown up with irrigation was much more rapid than could be expected of the slower-minded tribesmen. Accordingly, it would clearly be a mistake to transfer tribesmen directly from the range to the severalty holding; there should be (as indeed experience has shown in dealing with the Indians) an intermediate period of proprietary training on collective reservations. The researches indicate that this period should cover at least a generation; in most cases two generations would be required for the development of that sentiment of thrift and feeling of independence required for successful citizenship. Some of the results of the year's work have been made public in scientific papers and addresses, and progress has been made in arranging the material for formal issue in reports.

In connection with his linguistic researches in British Columbia, Dr. John R. Swanton collected definite information concerning the kinship terms and other factors in the social organization of the Haida Indians, and toward the close of the year he made progress in arranging the data for publication.

WORK IN PHILOLOGY.

During the earlier part of the fiscal year the Director continued the arrangement of Mexican and Central American linguistic material with a view to the classification of the aborigines of the southern portion of North America on a linguistic basis. As during the preceding year, Dr. Cyrus Thomas collaborated in the work. The completion of the task was delayed by the illness of the Director during the later months of the year.

At the opening of the year Prof. Franz Boas, of Columbia University, was given an honorary appointment as philologist, and was intrusted with the supervision of a considerable part of the linguistic researches in which the Bureau is engaged. One of the objects of the appointment was that of obtaining a uniform series of outlines of Indian languages to be published in synoptic form for use in comparative studies by the philologists of the world. The work requires extensive preparation because of the wide range and considerable volume of the material both in hand and required. At the time of discovery there were in North America somewhere between one and two thousand tribal dialects or languages belonging to about a hundred linguistic stocks or families, so that the scope of the work is so broad that it may not be accomplished except by the cooperation of many specialists devoted to particular groups of languages. Under existing conditions it seems inexpedient to attempt covering the ground through the Bureau alone; and the plan of the work intrusted to Dr. Boas is to enlist the cooperation of other institutions and other linguistic specialists. During the past year the work was organized in cooperation with the American Museum of Natural History, Columbia University, Harvard University, and the University of California. The collaborators included Dr. John R. Swanton, of the Bureau; Mr. H. H. St.

Clair, 2d, of the American Museum; Mr. William Jones, on behalf of Columbia University; Dr. Roland B. Dixon, of Harvard, and Dr. A. L. Kroeber, under the auspices of the University of California. Dr. Swanton's work comprised the transcription of a voluminous series of Haida texts; he also completed a synopsis of the Haida language for incorporation in the general series. Mr. St. Clair devoted a part of the year to work on a dictionary and grammar of the Chinook language, and in addition made a critical study of Shoshone linguistic material in the archives of the Bureau and of the American Museum. Mr. Jones made good progress in analyzing the grammar of the Sauk and Muskwaki dialects, nearly completing a list of suffixes and prefixes; he also made good progress in arranging for publication a series of Muskwaki texts collected during the preceding fiscal year. Dr. Dixon prepared a grammar and vocabulary of the Maidu language, while Dr. Kroeber collected and arranged both lexic and grammatic material representing several other California tribes. Partly through the inspiration of hearty approval from scientists and scholars both at home and abroad, Dr. Boas and his collaborators have taken up the work with zeal and enthusiasm. Dr. Boas observes: "Linguistic work in many parts of North America is exceedingly urgent on account of the rapid disappearance of the native languages, and the means at our disposal for this work are insufficient;" yet it is a gratification to report that the interest of the collaborators who have worked gratuitously or for only nominal compensation has resulted in a large volume of invaluable material at trifling cost to the Bureau. It is a pleasure to acknowledge the generous contributions of Dr. Boas and the other collaborators named.

During the year Dr. Boas completed the proof revision of his memoir entitled "Kathlamet Texts," and it has been published as a bulletin. He also completed the manuscript for a similar memoir entitled "Tsimshian Text," and it was transmitted for publication on January 29, 1902.

Dr. Albert S. Gatschet carried forward to substantial completion his vocabulary and grammar of the Peoria language, and also continued the arrangement of material for the comparative Algonquian vocabulary. In addition he devoted some time to special researches required for answering some of the numerous requests for information concerning Indian terms and phrases constantly received from correspondents.

Mr. J. N. B. Hewitt devoted the greater part of the year to his monograph on Iroquois Creation Myths, mentioned in previous reports; three of the five sections were sent to press during the year as a part of the Twenty-first Annual Report. Toward the close of the year he took up the general discussion of principles noted in another paragraph; and as a part of the current work, he continued the extraction and arrangement of Iroquoian linguistic material in a form suitable for reference and eventually for publication. Throughout the year a considerable part of Mr. Hewitt's time was occupied in the researches required for answering technical inquiries from correspondents—a duty which seems unavoidable, although its performance retards progress in systematic researches.

Miss Jessie E. Thomas continued the transcription of the manuscript Diccionario de Motul, while Señor Andomaro Molina, of Merida, Yucatan, made good progress in the translation of the Maya and Spanish terms into English, with a view to the issue of this extensive vocabulary in a form appropriate to the publications of the Bureau. In view of the prospective value of this work to future students, it would seem important that the final translation should be based on thorough and critical knowledge of the Maya, Spanish, and English languages; and in view of this desirability, in connection with the fact that Señor Molina is a volunteer collaborator resident in another country, it is deemed proper to insert the following voluntary expression from the United States consul at Progreso, Yucatan, Hon. Edward H. Thompson, himself a critical student of the antiquities, history, and languages of Yucatan: "To my mind, in the work of Lic. Andomaro Molina, the Bureau

has done the best work of the year and has done it in the best possible way. It has arranged to give to light and study a much-needed work, and it has put it in the very hands best fitted to do it. I am, perhaps, competent to speak upon this subject, and I am willing to place on record my belief that no living man can do this work intrusted to him so well as Mr. Molina. The work that he is doing can not be done by a foreigner. I am, perhaps, as well informed upon the native Maya, their habits, customs, etc., as any living foreigner, and, it may be, better than any other. I know enough to know that I could not do the work as it should be done. This task should only be undertaken by one who has been brought up on milk from a native breast, whose first words were in Maya, and whose thoughts come easier to him when clothed in the Maya form than when in classic Castillian or downright Anglo-Saxon. Such a man is Molina. To the instincts and the education of a scholar he adds the subtile understanding of the native and as perfect command of the ancient language, the Maya, as any man can have at this day."

The final proofs of the Natick Dictionary, compiled by the late James Hammond Trumbull, were revised during the year, and the greater part of the sheets have been printed.

In addition to his work on the Mexican and Central American linguistic records, in immediate collaboration with the Director, Dr. Cyrus Thomas continued his investigation of aboriginal records in the form of codices, sculptures, etc. His work was productive, yielding among other results a memoir entitled Quirigua Calendar Systems, which was sent to press as a part of the Twenty-second Annual Report.

Progress was made also in preparing for the press the translations made by Mr. Charles P. Bowditch of certain scattered yet noteworthy contributions to knowledge concerning the calendric and other records of Mexico and Central America, and it is a pleasure to acknowledge the generosity of the translator in contributing the material and furthering the work of its preparation in every practicable way. Toward the end of the fiscal year Mr. Elbert J. Benton was temporarily employed to edit the material and arrange the illustrations for publication in the Twenty-fourth Annual Report; this work was well advanced at the close of the year.

WORK IN SOPHIOLOGY.

About the end of May Miss Alice C. Fletcher completed her monograph on the Pawnee Indians under the title "Hako; A Pawnee Ceremony." In many respects a typical tribe of the plains, the Pawnee Indians were in some points the most remarkably developed of the prairie tribes. Like other vigorous aboriginal groups, they were composite; an important constituent (later known as the Skidi band) was from the wooded hills and broad bottom lands of the Arkansas country, where they or their ancestry developed a woodland culture, and doubtless performed a share in the erection of the imposing mounds of the Lower Mississippi region; other tribal constituents represented prairie provinces; and there are strong suggestions in the rich tribal mythology that at least a cultural constituent was absorbed from the highly religious sedentary peoples of the Southwestern pueblos. Then the composite tribe lived long (as attested by their traditions as well as their customs) in the prairie region, which they shared with the buffalo; and, in even greater degree than the Siouan tribes farther northward, they adjusted themselves to this natural spoil—so that the buffalo became the furnisher of their food, the source of their raiment, the giver of material for their habitations, the guide of their migrations, the goal of their handicraft and hunting tactics, and, finally, one of the foremost among their deified tutelaries. Accordingly the fiducial ceremonies of the tribe combine the intensity of local veneration for a few leading tutelaries with a wealth of imagery and ritual derived from other districts and peoples, and all vivified by the common union and interaction. During earlier days the rituals were so far esoteric as generally to escape the notice of ethnologists as well as casual visitors; but during recent years a few students, notably Miss Fletcher, have been per-

mitted to enter the arcana and witness the sacred ceremonies, and even to examine and obtain interpretations of the magic "bundles" which serve as the tangible basis of the rituals. All of these rituals are impressive; some, like the Hako, are of remarkable richness, not only in gesture and measured movement, but in the poetic imagery expressed in word and music and pantomime. Miss Fletcher's record appears to be perfect, and she has analyzed with acumen the rhythm and melody of the chants, the symbolic harmony of the accompanying pantomime, and the meaning expressed in the intricate figures of the dance and movements of the march forming essential features of the ceremony. From Miss Fletcher's rendition and interpretations it would seem that these elaborate rituals open a vista looking directly on the beginnings of song, dance, drama, poesy—certainly they are a revelation to students of the highest phases of human culture as well as to the investigator of primitive customs. The memoir is in press as a part of the Twenty-second Annual Report.

In connection with his comparative study of Indian creation myths, Mr. Hewitt has been led to analyze certain fundamental features of primitive philosophy, especially those forming the basis of totemism, shamanism, etc. It is well known that in the different Indian languages there are terms difficult of translation into modern tongues which are of deep meaning to their users, e. g., *manido*, or *manitou*, among the Algonquian tribes, *wakan*, or *wakanda*, among the Siouan tribes—terms covering a larger proportion and wider variety of the thought of primitive men than any single term covers in higher culture. Among the Iroquoian Indians the corresponding term is *orenda*, which may be translated "mysterious power for good and evil," "powers of magic," or, more briefly, "magic potency." Mr. Hewitt's analysis was announced in a preliminary paper, and has already proved serviceable to ethnologists in this and other countries; and it seems probable that the Iroquois term will come into general use in the English language for purposes of sophiologic discussion. The complete study is designed for publication in the second part of "Iroquois Creation Myths," which was nearly ready for the press at the end of the year.

For a number of years Mrs. Matilda Coxe Stevenson has been investigating the myths and ceremonies of the Zuñi Indians, the progress of the work being retarded by her ill health, as noted in previous reports. During the earlier months of the fiscal year Mrs. Stevenson was on temporary furlough, and the state of her health so improved as to permit her to take up the work again. Accordingly she was able to finish the revision of several incomplete chapters and to arrange the material for the entire monograph in form for publication. The nature and extent of the work have been reported repeatedly; it may be noted merely that Mrs. Stevenson's ambition has been to make a model record of the elaborate ceremonies of one of the most interesting of the Pueblo tribes, and that it is a source of much gratification to announce the satisfactory completion of the work.

Although their researches were devoted primarily to other Indian activities, several of the collaborators have made noteworthy collections of sociologic material during the year, the work of Dr. Fewkes on Porto Rican zemis and zemeism, that of Mr. Mooney on the fiducial factors in Kiowa heraldry, that of Dr. Russell on the calendric systems and accompanying beliefs of the Pima Indians, that of Dr. Jenks on the mythology of birch bark, and that of Dr. Swanton on the mythologic features of social organization among the Haida Indians being especially worthy of mention.

DESCRIPTIVE ETHNOLOGY.

In connection with his field work, Mr. Mooney was able to make some progress in the preparation of the Cyclopedia of Native Tribes; and when other duties permitted, Dr. Thomas continued the collection of material for this work, both from current publications and from the rare books constantly being added to the library.

About the middle of the year the Hilder translation of the manuscript history of

Texas by Padre Morfi was taken up for annotation with a view to publication. The historical annotation was kindly undertaken by Dr. George P. Garrison, of the University of Texas, and the manuscript was in his hands at the close of the year.

COLLECTIONS.

All of the collaborators engaged in field operations made more or less extensive collections for study and for ultimate transfer to the United States National Museum. By far the most extensive of these collections was that made by Mr. Mooney as a means for the research in heraldry. This collection still remains in the field. Dr. Russell collected a full series of objects representing the arts and industries of the Pima Indians, including a series of baskets representing the more archaic as well as the modern forms; among the unique objects comprised in the collection are two calendric records intermediate in character between the winter counts of the North and the maguey-book records of the South. Dr. Fewkes made considerable collections in New Mexico and Chihauhua early in the year, and subsequently obtained an interesting series of aboriginal objects in Porto Rico. As usual, various collections were obtained also by purchase under the more immediate direction of the Secretary.

PROPERTY.

The property of the Bureau comprises (1) office furniture and apparatus, (2) ethnologic manuscripts and other original records, (3) photographs and drawings of Indian subjects, (4) collections held temporarily by collaborators for use in research, (5) a working library, and (6) undistributed residues of the editions of the Bureau publications. There was little change in the amount or value of office property during the year. Purchases of office furniture were inconsiderable; several manuscripts were acquired by purchase, mostly for immediate publication, as noted in previous paragraphs, while the records of original work progressed steadily; about 855 negatives (glass and film), 2,050 prints, and a number of drawings were added to the collection of illustrative material, and an approximately proportionate quantity of illustrative material was used in the reports. Most of the collections of the year have gone directly to the United States National Museum; some, like those of Mr. Mooney, are still in use. The library has maintained a steady growth, chiefly through exchanges, partly by the purchase of current ethnologic books and early records pertaining to the aborigines. The additions of the year comprise about 895 books and 150 pamphlets, raising the contents of the library to 11,339 books and 2,500 pamphlets. The number of back reports was reduced through the constantly increasing public demands for ethnologic literature; nearly all of these documents are now out of print. During the first half of the fiscal year Mr. J. Julius Lund continued in charge of the property as custodian; after Mr. Lund's resignation Mr. Frank M. Barnett was appointed to this position. Miss Jessie E. Thomas remains in immediate charge of the library and Miss Ella Leary of the distribution of documents.

PUBLICATIONS.

At the beginning of the year Mr. Herbert S. Wood had charge of the editorial work; subsequently he was furloughed for several months, when Dr. Albert E. Jenks assumed editorial duties in connection with his researches; in June Mr. Wood resumed his editorial capacity, and toward the end of May Mr. Elbert J. Benton was temporarily added to the corps as editorial assistant. The second part of the Eighteenth Report was delivered from the bindery on January 7, and was immediately distributed; Bulletin 26 was delivered on March 11, and, after brief holding in the hope that the Nineteenth Report might be distributed at the same time, was sent out to the exchanges about the end of the year; separate copies of the papers composing

the Nineteenth Report were delivered in March, but the binding of the volumes was delayed by reason of unusual conditions in the Printing Office, and the edition was not delivered at the end of the year. On January 29 the Twentieth Annual Report was transmitted. It is designed for publication in one volume, and comprises, in addition to the formal report, the Holmes monograph on aboriginal pottery. The Twenty-first Annual Report was transmitted for printing on March 12. It, also, is designed to form one volume, comprising, in addition to the formal report, the memoirs on Hopi Katcinas, by Dr. Fewkes, and Iroquois Creation Myths, by Mr. Hewitt. On June 30 the Twenty-second Annual Report was transmitted for publication in two volumes. It comprises, in addition to the administrative report, Two Summers' Work in Pueblo Ruins, by Dr. Fewkes, Quirigua Calendar Systems, by Dr. Thomas, and Hako: A Pawnee Ceremony, by Miss Fletcher. On January 29 Dr. Boas's memoir entitled Tsimshian Texts was transmitted for publication in bulletin form. At the close of the year material was in hand for the Twenty-third Report and for the greater part of the Twenty-fourth.

Mr. De Lancey Gill remained in charge of the illustrative work, preparing copy for, and revising proofs of, the illustrations for the Twentieth and later reports. He also made photoportraits of some 200 Indians, chiefly members of delegations visiting Washington, and developed a considerable number of negatives made by the several collaborators in the field, and, in addition, he made a useful series of field photographs in connection with the work of Professor Holmes in Indian Territory, as noted elsewhere. As heretofore, he was assisted by Mr. Henry Walther.

I have the honor to be, yours with respect,

W J McGee, *Acting Director.*

Hon. S. P. Langley,
Secretary, Smithsonian Institution, Washington, D. C.

Appendix III.

REPORT ON THE OPERATIONS OF THE INTERNATIONAL EXCHANGE SERVICE.

Sir: I have the honor to submit the following report of the operations of the International Exchange Service during the year ending June 30, 1902:

The work pertaining to exchanges is confined to the southeast basement of the Smithsonian building. The rooms, five in number, extend along the south front for a distance of 144 feet, and in the main were especially constructed nine years ago for the exclusive use of the Exchange Service. Considerable space has since been added, making the shipping room much larger, and various improvements have been introduced to facilitate the handling of packages.

The equipment of the Exchange offices is especially adapted to the peculiarities of the work, and consists, in addition to the necessary desks and their usual accessories, of several sorting tables for folding and arranging parcels, a large number of bins (each of which is used as the receptacle of all parcels for a single country until a sufficient quantity shall have accumulated to make a minimum shipment), cases for reference books and directories, filing cases for ledger cards (upon which are recorded accounts of all exchanges with each correspondent), and cabinets for filing receipt and index cards and for general correspondence. Other articles of office furniture are typewriters, scales, trucks, etc.

It is pertinent to state that most of the articles of office furniture and fixtures have been purchased from Smithsonian funds, the Congressional appropriations having been sufficient only for the payment of most of the salaries, a part of the transportation expenses, and the purchase of expendable supplies for packing and office use.

Since the last report of the Exchange Service, there have been no extensive additions to the general equipment of the Exchange offices except the construction of an hydraulic elevator for raising and lowering exchanges to and from the loading platform, and the placing of a scale with a weighing capacity of 2,500 pounds near the elevator shaft. The expense incurred by both these improvements was borne by the Institution.

During the last fiscal year there has been no loss of exchanges transmitted to the Institution from abroad, so far as known, and but one instance in which outgoing exchanges have been lost or even damaged. The latter occurred February 1, 1902, when three boxes of exchanges for correspondents in South Australia were entirely destroyed by water while a fire was being extinguished in the hold of the steamship *Bucrania*, which was loading at Brooklyn, N. Y. Each contributor was notified of the loss, as is the custom of the Institution in such cases, with the result that most of the publications were duplicated.

The work performed by the Exchange Service during the year and the extent to which the influence of the service is felt throughout the civilized world is shown in its various features by the accompanying tables.

During the year 38,647 packages were received from abroad for distribution, and 87,149 packages of domestic publications were sent to correspondents outside the United States, making a total of 125,796. The aggregate weight of these exchanges was 396,418 pounds, or an average of little over 3 pounds per package. It will thus be seen, by comparison with the last report, that while the total weight of the exchanges received and transmitted during the year 1900–1901 exceeded those of the year following by 17,859 pounds, the number of packages handled during the latter year exceeded those of the preceding year by 4,736.

The number of packages received from abroad for United States Government establishments aggregated 11,290, while those sent under authority of Congress and by United States Government departments and bureaus numbered 52,871. Eliminating

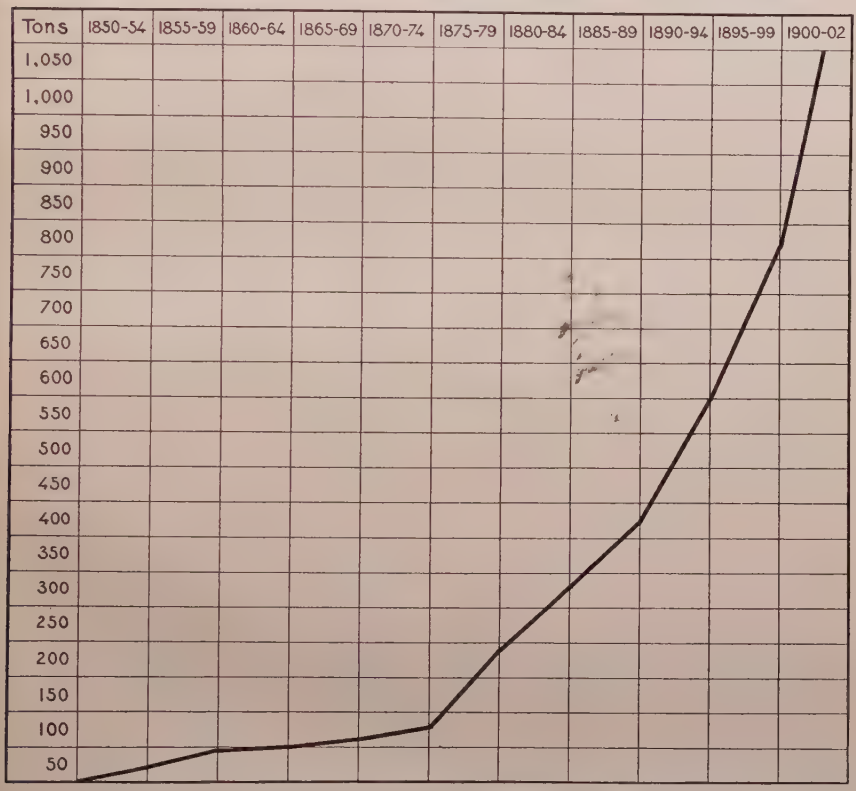


FIG. 1.—Chart representing the increase of exchange transmissions in tons of 2,000 pounds, from 1850 to 1902, divided into periods of five years.

all transmissions in behalf of the United States Government, the scientific publications forwarded or received by societies and individuals aggregated 34,278 outgoing and 27,357 incoming.

The several classes and the number of packages in each class, together with the percentage which each subdivision bears to the whole, are as follows:

United States Government exchanges, 51 per cent:

Sent to designated depositories abroad under the act of March 2, 1867	25,358	
Sent by United States Government establishments	27,513	
Received from abroad for the Library of Congress	5,946	
Received for all other United States Government institutions	5,344	
		64,161

Scientific and miscellaneous exchanges, 49 per cent:

Sent abroad	34,278	
Received from abroad	27,357	
		61,635
Total		125,796

It is not possible to give the actual weights of each class of exchanges, but it is estimated that in the aggregate the publications sent and received for the various

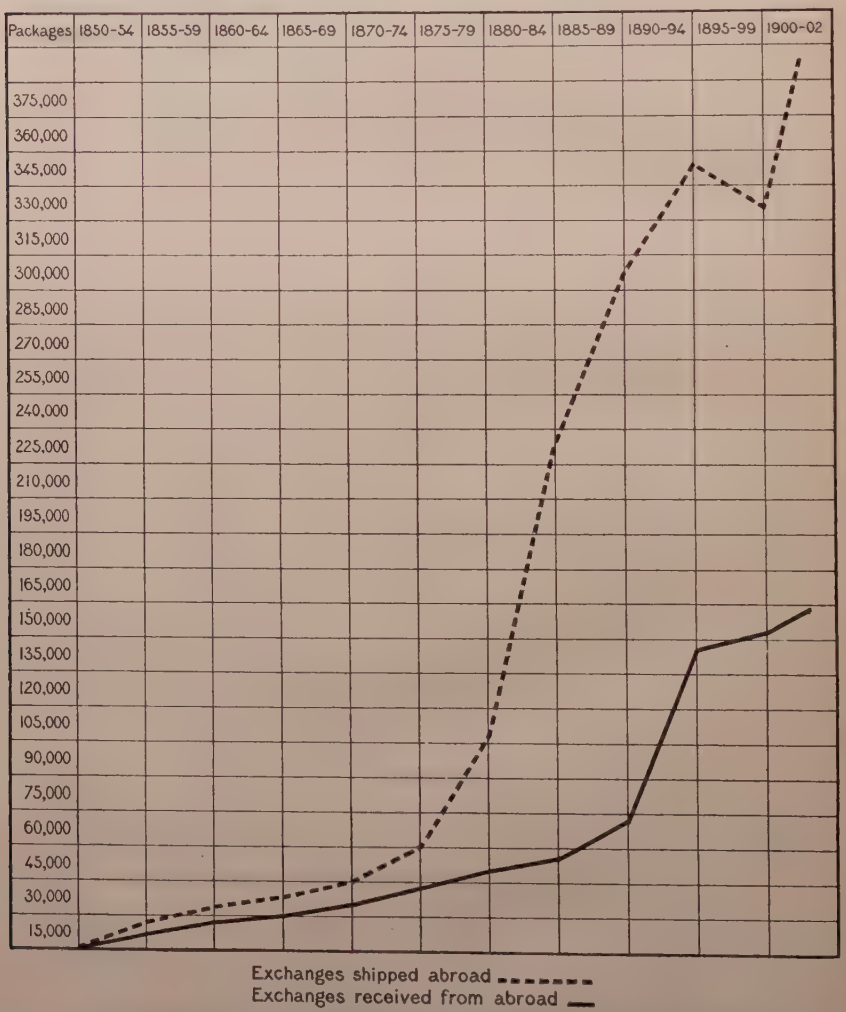


FIG. 2.—Chart representing the increase of exchange transmissions abroad from 1850 to 1902, and also of those received from abroad for distribution in the United States during the same period.

Government establishments weighed about 65 per cent of the total of all transmissions for the year, or about 258,000 pounds.

By comparison, the receipts from abroad are far from being a satisfactory equivalent of those sent, especially with regard to governmental exchanges. This inequality is gradually being adjusted by some countries, and it is hoped that in the not distant future the exchanges from abroad may be considerably increased. In this

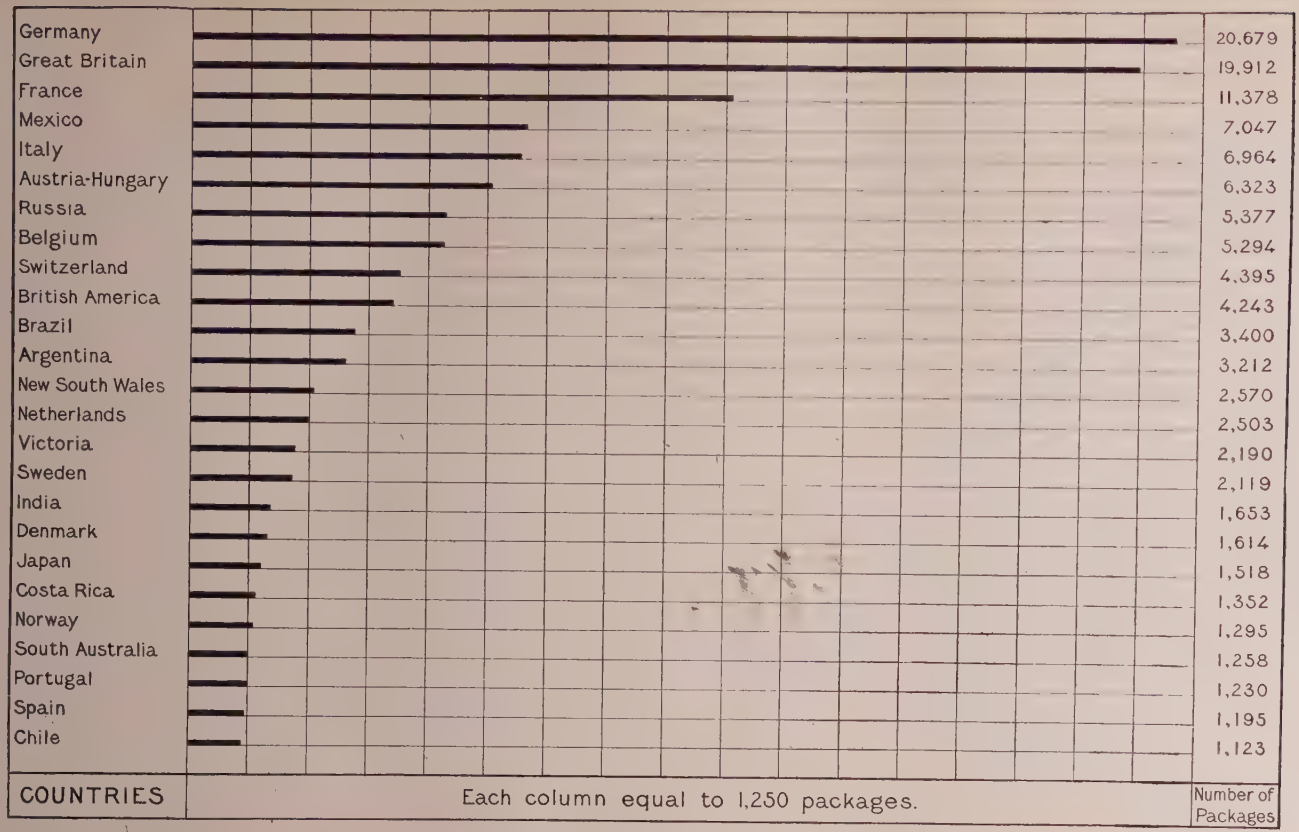


CHART REPRESENTING THE RELATIVE NUMBER OF PARCELS EXCHANGED BETWEEN THE UNITED STATES AND OTHER COUNTRIES DURING THE FISCAL YEAR ENDING JUNE 30, 1902.

Exchanges were conducted with 126 countries. Those aggregating less than 1,000 packages are omitted.

connection I beg leave to suggest that were a representative of the Institution constantly on the ground, devoting his attention to the requirements, not only of our national library, but of the various departmental libraries in the matter of exchanges, the returns for the publications now so generously distributed by the United States would soon be greatly increased, if not quite equalized.

Following are the total number of parcels sent and received during the year:

Shipments, 69 per cent:		
United States Government exchanges	52,871	
Scientific and miscellaneous exchanges	34,278	
		87,149
Receipts, 31 per cent:		
United States Government exchanges	11,290	
Scientific and miscellaneous exchanges	27,357	
		38,647
Total parcels		125,796

The number of correspondents in the United States has reached a total of 8,739, the increase during the year having been 590. There are now 38,200 names of libraries and individuals on the records of the Exchange Service, representing an increase of 2,495 names during the year.

The sum appropriated by Congress for the support of the International Exchanges during the fiscal year was $24,000, being the same as that granted for each of the two immediately preceding years. The attention of Congress, through its committees, was called by the Secretary to the inadequacy of the appropriation on account of the steady increase in the work of the service, the improvement inaugurated therein by substituting ocean express for freight as a medium of transportation, and the additional requirements that the Institution would be obliged to meet by reason of the adoption by Congress on March 2, 1901, of a resolution requiring the Public Printer to deliver to the Library of Congress, for its own use and for international exchange, 62 instead of 50 sets of Government publications, "except as such number shall be enlarged to not exceed 100 copies by request of the Librarian of Congress." On this account Congress, in its sundry civil act approved June 28, 1902, saw fit to grant an increase of $2,000, or $26,000 in all, for the next fiscal year.

Owing to a readjustment of the duties of the deputy collectors of the port of New York, Mr. Charles A. King succeeded Mr. John C. Williams on February 7, 1902, as the officer designated by the collector to enter and care for international exchanges arriving from abroad.

Despite the constant endeavors of the Institution to establish more adequate exchange relations with the Governments of Japan and China, all efforts in that direction have thus far been futile. Only exchanges for governmental and native educational institutions in Japan can be distributed under the present arrangement, and all other contributions are therefore discouraged. In China no facilities are provided for the official distribution of exchanges, and the Institution has no means of distributing parcels in the Empire except those bearing addresses in Shanghai, which are delivered by the courtesy of the Zi-ka-we. Observatory.

Thus far Great Britain, Germany, and Austria-Hungary have not adopted the custom prevailing elsewhere in Europe of officially providing for an international exchange of publications, and the Smithsonian Institution, with the aid of funds provided for the support of the Exchange Service, has been obliged to maintain salaried agents in each of these countries and to bear the expense of distribution of parcels as well as for transporting the publications of those countries to the United States. It is hoped, however, that the steps that have been taken from time to time to adjust this inequality in the exchange system may eventually be successful.

The Institution has been especially fortunate in the selection of its agents in those countries where no provision has been made officially for conducting exchanges.

Dr. Felix Flügel, Messrs. William Wesley & Son, and Dr. Joseph von Kőrösy, located at Leipzig, London, and Budapest, respectively, have faithfully served the Institution for many years. Dr. Flügel has given constant attention to the service for nearly half a century, while the Messrs. Wesley have acted as the agents of the Institution since 1862.

Tabular statement of the work of the International Exchange Service during the fiscal year 1901–1902.

Date.	Number of packages handled.	Weight of packages handled.	Number of correspondents June 30, 1902.				Packages sent to domestic addresses.	Cases shipped abroad.
			Foreign societies.	Domestic societies.	Foreign individuals.	Domestic individuals.		
1901.								
July	16,452	55,559						
August	9,348	22,299						
September	5,660	36,049						
October	12,197	29,394						
November	6,903	23,585						
December	10,344	31,866						
1902.								
January	12,736	42,485						
February	6,627	17,109						
March	12,714	59,545						
April	8,041	20,470						
May	9,842	26,079						
June	14,932	31,978						
Total	125,796	396,418	11,760	3,182	17,701	5,557	33,961	1,847
Increase over 1900–1901	4,736	a17,859	465	186	1,440	404	2,594	90

a Decrease.

The following table shows the number of packages of exchanges handled and the increase in the number of correspondents each year from 1895 to 1902:

	1895–96.	1896–97.	1897–98.	1898–99.	1899–1900.	1900–1901.	1901–1902.
Number of packages received	88,878	81,162	84,208	97,835	113,563	121,060	125,796
Weight of packages received, pounds	258,731	247,444	301,472	317,883	409,991	414,277	396,418
Correspondents:							
Foreign societies	8,022	9,414	10,165	10,322	10,845	11,295	11,760
Foreign individuals	10,878	12,013	12,378	13,378	15,385	16,261	17,701
Domestic societies	2,115	2,445	2,533	2,596	2,721	2,996	3,182
Domestic individuals	3,899	4,136	4,382	4,673	5,000	5,153	5,557
Packages to domestic addresses	34,091	23,619	21,057	30,645	28,625	31,367	33,961
Cases shipped abroad	1,043	1,300	1,330	1,500	1,768	1,757	1,847

CORRESPONDENTS.

The record of exchange correspondents at the close of the year contained 38,200 addresses, being an increase of 2,495 over those of the preceding year. The following table gives the number of correspondents in each country and also serves to illustrate the scope of the service.

Number of correspondents of the International Exchange Service in each country on June 30, 1902.

Country.	Correspondents.		
	Libraries.	Individuals.	Total.
AFRICA.			
Algeria	22	27	49
Angola	1		1
Azores	5	15	20
Beira		1	1
British Central Africa		1	1
British East Africa		1	1
Canary Islands	1	6	7
Cape Colony	42	78	120
Cape Verde Islands		4	4
Congo Free State		3	3
Egypt	30	52	82
French Congo		1	1
Gambia		2	2
Gold Coast		2	2
Lagos	2	2	4
Liberia	2	4	6
Lourenço-Marquez		2	2
Madagascar	2	6	8
Madeira	3	4	7
Mauritius	12	7	19
Morocco		10	10
Mozambique		1	1
Natal	14	18	32
Orange River Colony		1	1
Reunion	2		2
St. Helena	3	2	5
Senegal		3	3
Sierra Leone	1	3	4
Transvaal	16	10	26
Tunis	8	9	17
Zanzibar		5	5
AMERICA (NORTH).			
Canada	275	501	776
Central America:			
British Honduras	4	7	11
Costa Rica	26	34	60
Guatemala	41	58	99
Honduras	11	29	40
Nicaragua	14	37	51
Salvador	16	11	27
Greenland	2		2
Mexico	156	169	325
Newfoundland	12	18	30
St. Pierre-Miquelon	2	2	4
United States	3,182	5,557	8,739
West Indies:			
Anguilla		1	1
Antigua	6	4	10
Bahamas	4	11	15

Country.	Correspondents.		
	Libraries.	Individuals.	Total.
AMERICA (NORTH)—continued.			
West Indies—Continued.			
Barbados	9	12	21
Bermuda	6	13	19
Buen Ayre		1	1
Cuba	46	112	158
Curaçao	1	4	5
Dominica	2	7	9
Grenada	3	5	8
Guadeloupe	2	5	7
Haiti	6	16	22
Jamaica	15	34	49
Martinique		1	1
Montserrat		2	2
Nevis		1	1
Porto Rico	4	20	24
St. Barthlomew		2	2
St. Christopher	2	4	6
St. Croix	1	3	4
St. Eustatius		1	1
St. Martin		2	2
St. Lucia	2	4	6
St. Thomas	2	4	6
St. Vincent	1	2	3
Santo Domingo	3	11	14
Tobago		1	1
Trinidad	14	11	25
Turks Islands	3	5	8
AMERICA (SOUTH).			
Argentina	136	128	264
Bolivia	16	11	27
Brazil	123	142	265
Britisn Guiana	16	10	26
Chile	78	88	166
Colombia	32	49	81
Dutch Guiana	4	3	7
Ecuador	14	20	34
Falkland Islands		6	6
French Guiana	1	2	3
Paraguay	18	9	27
Peru	37	60	97
Uruguay	40	29	69
Venezuela	32	44	76
ASIA.			
Arabia		7	7
Borneo		1	1
British Burma	9	8	17
British New Guinea		1	1
British North Borneo		1	1

Number of correspondents of the International Exchange Service in each country on June 30, 1902—Continued.

Country.	Correspondents.			Country.	Correspondents.		
	Libraries.	Individuals.	Total.		Libraries.	Individuals.	Total.
ASIA—continued.				EUROPE—continued.			
Celebes		2	2	Denmark	104	161	265
Ceylon	21	12	33	France	1,634	2,001	3,635
China	43	91	134	Germany	2,304	3,266	5,570
Cochin China	4	4	8	Gibraltar	1	4	5
Cyprus	2	4	6	Great Britain	1,879	4,209	6,088
Formosa		3	3	Greece	39	37	76
French East Indies	1	1	2	Iceland	16	8	24
Hongkong	7	20	27	Italy	786	828	1,614
India	210	193	403	Luxemburg	10	4	14
Japan	135	310	445	Malta	9	11	20
Java	17	27	44	Montenegro	1	1	2
Korea	2	8	10	Netherlands	192	276	468
Macao		1	1	Norway	120	129	249
New Guinea		1	1	Portugal	100	74	174
Persia	3	9	12	Roumania	32	58	90
Philippine Islands	10	14	24	Russia	461	759	1,220
Portuguese India	1		1	Servia	20	12	32
Sarawak	1		1	Spain	171	192	363
Siam	5	17	22	Sweden	174	268	442
Straits Settlements	11	12	23	Switzerland	335	552	887
Sumatra		4	4	Turkey	34	75	109
AUSTRALASIA.				POLYNESIA.			
New South Wales	72	121	193	Fiji Islands	1	3	4
New Zealand	73	88	161	German New Guinea		1	1
Queensland	33	51	84	Hawaiian Islands	25	40	65
South Australia	43	65	108	Marshall Islands		1	1
Tasmania	17	17	34	New Caledonia		2	2
Victoria	94	126	220	New Hebrides	1		1
Western Australia	21	27	48	Samoa		5	5
EUROPE.				Tahiti		3	3
Austria-Hungary	702	1,018	1,720	Tonga		2	2
Belgium	322	391	713	International	36		36
Bulgaria	12	18	30	Total	14,942	23,258	38,200

EXCHANGE OF GOVERNMENT DOCUMENTS.

The following table shows the number of packages forwarded and received by the several branches of this Government during the year. By comparison with the last report it will be observed that there has been a decrease of 1,614 in the receipts from abroad and an increase of 3,461 in the transmissions from United States Government establishments to their correspondents in other countries, or a net increase of 1,847, equal to 3 per cent, over last year.

Statement of Government exchanges during the year 1901–2.

Name of bureau.	Packages.	
	Received for—	Sent by—
Adjutant-General's Office		2
American Historical Association	9	118
Astrophysical Observatory	6	
Auditor for the State and other Departments		711
Board on Geographic Names	1	207
Bureau of American Ethnology	249	692
Bureau of American Republics	18	
Bureau of Education	115	25
Bureau of Medicine and Surgery	1	
Bureau of the Mint	7	367
Bureau of Navigation	16	118
Bureau of Statistics, Treasury Department	93	4,806
Bureau of Steam Engineering	1	
Census Office	17	764
Civil Service Commission	1	
Coast and Geodetic Survey	124	330
Commissioner of Internal Revenue		9
Commissioners of the District of Columbia	4	22
Comptroller of the Currency	4	160
Department of Agriculture	399	701
Department of the Interior	30	641
Department of Justice	2	
Department of Labor	36	64
Department of State	19	
Entomological Commission	3	
Engineer School of Application	1	
Fire Department of the District of Columbia		1
Fish Commission	96	715
General Land Office	3	
Geological Survey	582	3,043
Health Department of the District of Columbia	1	
Hydrographic Office	103	2
Interstate Commerce Commission	17	160
Library of Congress	5,946	25,358
Life-Saving Service	2	60
Light-House Board	3	278
Marine-Hospital Service	11	1
National Academy of Sciences	98	887
National Botanic Garden	1	
National Bureau of Standards	1	
National Museum	340	3,681
National Zoological Park	7	5
Nautical Almanac Office	35	105
Naval Observatory	143	1
Navy Department	12	
Office of the Chief of Engineers	25	72
Office of Indian Affairs	2	
Patent Office	119	862
President of the United States	1	
Record and Pension Office	1	147
Senate of the United States	1	
Smithsonian Institution	2,144	6,760
Superintendent of Documents	1	3
Surgeon-General's Office	159	290
Treasury Department	10	3
War Department	125	19
Weather Bureau	145	681
Total	11,290	52,871

RELATIVE INTERCHANGE OF PUBLICATIONS BETWEEN THE UNITED STATES AND OTHER COUNTRIES.

Following is a comparative statement of exchange transmissions by packages between the United States and other countries during the years 1901 and 1902:

Comparative statement of packages received for transmission through the International Exchange Service during the fiscal years ending June 30, 1901, and June 30, 1902.

Country.	1901. Packages.		1902. Packages	
	For—	From—	For—	From—
Algeria	113	74	108	106
Angola	3			
Antigua	7		17	
Arabia	5		10	
Argentina	2,374	392	2,426	787

Comparative statement of packages received for transmission through the International Exchange Service, etc.—Continued.

Country.	1901. Packages.		1902. Packages.	
	For—	From—	For—	From—
Austria-Hungary	4,531	2,518	4,480	1,843
Azores	14		10	
Bahamas	15		12	
Barbados	14		23	
Belgium	2,301	1,792	2,322	2,072
Bermudas	11		17	
Bolivia	84		315	11
Borneo	4		7	
Brazil	1,440	715	1,522	1,878
British America	2,532	706	3,291	952
British Burma	4		6	
British Guiana	57	1	71	
British Honduras	12		8	
British New Guinea			2	
Bulgaria	72	88	80	140
Canary Islands	6		5	
Celebes	1		1	
Cape Colony	274	1	279	1
Cape Verde Islands	2			
Ceylon	56		53	1
Chile	1,090	1	1,120	3
China	249	141	296	155
Colombia	657		691	
Costa Rica	784	673	773	579
Cuba	233	25	209	37
Curaçao	4		5	
Cyprus	2		5	
Denmark	1,054	186	1,052	562
Dominica	5		19	
Dutch Guiana	7		12	2
Ecuador	77		116	
Egypt	163		173	
Falkland Islands	3		3	
Fiji Islands	3		2	
Formosa	2		5	
France	8,037	2,525	8,077	3,301
French Cochin China	1		4	
French Guiana	1			
Germany	14,868	8,265	14,057	6,622
Gibraltar			3	
Goree Dakar			3	
Grenada	4		6	
Great Britain and Ireland	12,394	8,606	12,790	7,122
Greece	689		707	40
Greenland	3		6	
Guadeloupe	5		3	
Guatemala	129		153	
Guinea	3		1	
Haiti	510		515	
Hawaiian Islands	94		54	1
Honduras	51	23	59	119
Hongkong	76		80	
Iceland	44	1	41	

Comparative statement of packages received for transmission through the International Exchange Service, etc.—Continued.

Country.	1901. Packages.		1902. Packages.	
	For—	From—	For—	From—
India	1,410	159	1,451	202
Italy	4,340	1,275	4,423	2,541
Jamaica	90		94	
Japan	1,533	18	1,497	21
Java	203	144	170	125
Korea	20		52	
Lagos			1	
Liberia	42		45	
Lourenço Marquez			4	
Luxemburg	75		86	26
Madagascar	12		6	
Madeira	5		9	
Malta	23	2	30	
Martinique	3		3	
Mauritius	47		56	
Mexico	1,719	3,720	1,852	5,195
Montenegro			1	
Montserrat	1			
Morocco	4		6	
Natal	58	3	54	2
Netherlands	1,847	723	1,802	700
Nevis	1			
Newfoundland	27		32	
New South Wales	1,534	229	1,956	614
New Zealand	821	12	809	13
Nicaragua	58		81	
Norway	1,292	999	1,238	57
Paraguay	73	40	64	251
Persia	20		33	
Peru	723	15	699	1
Philippine Islands	61		45	5
Porto Rico	46		12	
Portugal	914		913	317
Queensland	814		815	2
Reunion	6		8	
Roumania	175	87	154	110
Russia	3,213	2,277	3,619	1,758
St. Croix	2		5	
St. Eustatius	1			
St. Helena	6		11	
St. Kitts	3		2	
St. Martin	2		3	
St. Pierre and Miquelon	2		1	
St. Thomas	2		7	
St. Vincent	3		1	
Samoa	13		11	
Santa Lucia	2		1	
Santo Domingo	9		10	
San Salvador	77	7	107	3
Servia	38		51	
Siam	54		39	
Sierra Leone	2	1	3	
Society Islands	1		3	

Comparative statement of packages received for transmission through the International Exchange Service, etc.—Continued.

Country.	1901. Packages. For—	1901. Packages. From—	1902. Packages. For—	1902. Packages. From—
South African Republic	542		548	
South Australia	764	92	1,055	203
Spain	1,219		1,194	1
Straits Settlements	46	1	54	18
Sumatra	4		2	
Sweden	1,909	292	1,843	276
Switzerland	2,431	686	2,358	2,037
Syria	22		35	
Tasmania	691	2	600	8
Tonga	12		5	
Trinidad	60		59	
Tunis	15	1	27	
Turkey	589		635	
Turks Islands	6		11	
United States	31,367	81,310	33,961	82,943
Uruguay	817	129	835	32
Venezuela	660		659	
Victoria	1,190	312	1,499	691
West Australia	656	335	664	43
Zanzibar	3		5	

The following is a list of the Smithsonian correspondents acting as distributing agents, or receiving publications for transmission to the United States, and of countries receiving regularly exchanges through the Institution:

Algeria. (*See* France.)
Angola. (*See* Portugal.)
Argentina: Museo Nacional, Buenos Ayres.
Austria: K. K. Statistische Central-Commission, Wien.
Azores. (*See* Portugal.)
Belgium: Commission Belge des Échanges Internationaux, Brussels.
Bolivia: Oficina Nacional de Inmigración, Estadística y Propaganda Geográfica, La Paz.
Brazil: Bibliotheca Nacional, Rio de Janeiro.
British Colonies: Crown Agents for the Colonies, London, England.
British Guiana. (*See* British Colonies.)
British Honduras. (*See* British Colonies.)
Bulgaria: Dr. Paul Leverkühn, Sofia.
Canada: Packages sent by mail.
Canary Islands. (*See* Spain.)
Cape Colony: Superintendent of the Stationery Department, Cape Town.
Chile: Universidad de Chile, Santiago.
China. (Shipments suspended for the present.)
Colombia: Biblioteca Nacional, Bogotá.
Costa Rica: Oficina de Depósito y Canje de Publicaciones, San José.
Denmark: Kong. Danske Videnskabernes Selskab, Copenhagen.
Dutch Guiana: Surinaamsche Koloniale Bibliotheek, Paramaribo.
Ecuador: Biblioteca Nacional, Quito.
East India: India Store Department, India Office, London.
Egypt: Société Khédiviale de Géographie, Cairo.
Fiji Islands. (*See* British Colonies.)

France: Bureau Français des Échanges Internationaux, Paris.
Friendly Islands: Packages sent by mail.
Germany: Dr. Felix Flügel, Aeussere Halle'sche Strasse 18, Leipzig-Gohlis.
Gold Coast. (*See* British Colonies.)
Great Britain and Ireland: William Wesley & Son, 28 Essex street, Strand, London, England.
Greece: Prof. R. B. Richardson, Director, American School of Classical Studies, Athens.
Greenland. (*See* Denmark.)
Guadeloupe. (*See* France.)
Guatemala: Instituto Nacional de Guatemala, Guatemala.
Guinea. (*See* Portugal.)
Haiti: Secrétaire d'Etat des Relations Extérieures, Port au Prince.
Honduras: Biblioteca Nacional, Tegucigalpa.
Hungary: Dr. Joseph von Körösy, "Redoute," Budapest.
Iceland. (*See* Denmark.)
Italy: Biblioteca Nazionale Vittorio Emanuele, Rome.
Jamaica. (*See* British Colonies.)
Java. (*See* Netherlands.)
Korea: Packages sent by mail.
Leeward Islands. (*See* British Colonies.)
Liberia: Care of American Colonization Society, Washington, District of Columbia.
Luxemburg. (*See* Germany.)
Madagascar. (*See* France.)
Madeira. (*See* Portugal.)
Malta. (*See* British Colonies.)
Mauritius. (*See* British Colonies.)
Mexico: Packages sent by mail.
Mozambique. (*See* Portugal.)
Natal: Agent-General for Natal, London, England.
Netherlands: Bureau Scientifique Central Néerlandais, Den Helder.
New Guinea. (*See* Netherlands.)
New Hebrides: Packages sent by mail.
Newfoundland: Packages sent by mail.
New South Wales: Board for International Exchanges, Sydney.
New Zealand: Colonial Museum, Wellington.
Nicaragua: Ministerio de Relaciones Exteriores, Managua.
Norway: Kongelige Norske Frederiks Universitet, Christiania.
Paraguay: Care Consul-General of Paraguay, Washington, District of Columbia.
Persia. (*See* Russia.)
Peru: Biblioteca Nacional, Lima.
Portugal: Bibliotheca Nacional, Lisbon.
Queensland: Chief Secretary's Office, Brisbane.
Roumania. (*See* Germany.)
Russia: Commission Russe des Échanges Internationaux, Bibliothèque Impériale Publique, St. Petersburg.
Saint Helena. (*See* British Colonies.)
Santo Domingo: Packages sent by mail.
San Salvador: Museo Nacional, San Salvador.
Servia. (*See* Germany.)
Siam: Board of Foreign Missions of the Presbyterian Church, New York.
South African Republic: William Wesley & Son, 28 Essex street, Strand, London.
South Australia: Astronomical Observatory, Adelaide.
Spain: Oficina para el Canje de Publicaciones Oficiales, Cientificas y Literarias. Seccion de Propiedad Intelectual del Ministerio de Fomento, Madrid.

Straits Settlements. (*See* British Colonies.)
Sumatra. (*See* Netherlands.)
Syria: Board of Foreign Missions of the Presbyterian Church, New York.
Sweden: Kongliga Svenska Vetenskaps Akademien, Stockholm.
Switzerland. Bibliothèque Fédérale, Berne.
Tasmania: Royal Society of Tasmania, Hobart.
Trinidad. (*See* British Colonies.)
Tunis. (*See* France.)
Turkey: American Board of Commissioners for Foreign Missions, Boston, Massachusetts.
Turks Islands. (*See* British Colonies.)
Uruguay: Oficina de Depósito, Reparto y Canje Internacional, Montevideo.
Venezuela: Biblioteca Nacional, Carácas.
Victoria: Public Library, Museum, and National Gallery, Melbourne.
Western Australia: Victoria Public Library, Perth.
Zanzibar: Packages sent by mail.

The distribution of exchanges to foreign countries was made in 1,847 cases, 466 of which contained official documents for authorized depositories, and the contents of 1,381 cases consisted of Government and other publications for miscellaneous correspondents. Of the latter class of exchanges the number sent to each country is given below:

Argentina	37	Natal	1
Austria	59	New South Wales	39
Belgium	42	Netherlands	37
Bolivia	4	New Zealand	8
Brazil	30	Nicaragua	5
British Colonies	6	Norway	20
Cape Colony	6	Paraguay	2
China	1	Peru	10
Chile	19	Polynesia	(a)
Colombia	9	Portugal	13
Costa Rica	12	Queensland	5
Cuba	(a)	Roumania	(c)
Denmark	20	Russia	57
Dutch Guiana	(b)	Salvador	5
Ecuador	5	San Domingo	1
East India	13	Servia	(c)
Egypt	3	Siam	(a)
France and Colonies	118	South Australia	18
Germany	212	South African Republic	(d)
Great Britain and Ireland	276	Spain	20
Greece	6	Sweden	43
Guatemala	6	Switzerland	43
Haiti	1	Syria	(a)
Honduras	4	Tasmania	3
Hungary	22	Turkey	(a)
Italy	67	Uruguay	10
Japan	19	Venezuela	11
Liberia	2	Victoria	25
Mexico	(a)	Western Australia	6

[a] Packages sent by mail.
[b] Included in transmissions to Netherlands.
[c] Included in transmissions to Germany.
[d] Included in transmissions to Great Britain.

The following is a list of depositories abroad to which sets of United States Government publications are sent under the joint resolution of Congress approved March 2, 1867. One box of current publications was forwarded to each depository on July 8 and October 24, 1901, and on January 4, March 17, and June 17, 1902.

Argentina: Library of the Foreign Office, Buenos Ayres.
Australia: Commonwealth of Australia, Melbourne.
Austria: K. K. Statistische Central-Commission, Wien.
Baden: Universitäts-Bibliothek, Freiburg.
Bavaria: Königliche Hof-und Staats-Bibliothek, München.
Belgium: Bibliothèque Royale, Brussels.
Brazil: Bibliotheca Nacional, Rio de Janeiro.
Buenos Ayres: Library of the Government of the Province of Buenos Ayres, La Plata.
Canada: Parliamentary Library, Ottawa.
Chile: Biblioteca del Congreso, Santiago.
Colombia: Biblioteca Nacional, Bogotá.
Costa Rica: Oficina de Depósito y Canje de Publicaciones, San José.
Denmark: Kongelige Bibliotheket, Copenhagen.
England: British Museum, London.
France: Bibliothèque Nationale, Paris.
Germany: Deutsche Reichstags-Bibliothek, Berlin.
Greece: National Library, Athens.
Haiti: Secrétaire d'Etat des Relations Extérieures, Port au Prince.
Hungary: Hungarian House of Delegates, Budapest.
India: Secretary to the Government of India, Calcutta.
Ireland: National Library of Ireland, Dublin.
Italy: Biblioteca Nazionale Vittorio Emanuele, Roma.
Japan: Foreign Office, Tokyo.
Manitoba: Legislative Library, Winnipeg.
Mexico: Museo Nacional, Mexico.
Netherlands: Library of the States General, The Hague.
New South Wales: Board for International Exchanges, Sydney.
New Zealand: General Assembly Library, Wellington.
Norway: Departementet for det Indre, Christiania.
Ontario: Legislative Library, Toronto.
Peru: Biblioteca Nacional, Lima.
Portugal: Bibliotheca Nacional, Lisbon.
Prussia: Königliche Bibliothek, Berlin.
Quebec: Legislative Library, Quebec.
Queensland: Parliamentary Library, Brisbane.
Russia: Imperial Public Library, St. Petersburg.
Saxony: Königliche Bibliothek, Dresden.
South African Republic: Department of Foreign Affairs, Pretoria.
South Australia: Parliament Library, Adelaide.
Spain: Seccion de Propriedad Intelectual del Ministerio de Fomento, Madrid.
Sweden: Kongliga Biblioteket, Stockholm.
Switzerland: Bibliothèque Fédérale, Berne.
Tasmania: Parliamentary Library, Hobart.
Turkey: Minister of Public Instruction, Constantinople.
Uruguay: Oficina de Depósito, Reparto y Canje Internacional de Publicaciones, Montevideo.
Venezuela: Biblioteca Nacional, Carácas.
Victoria: Public Library, Melbourne.
Western Australia: Victoria Public Library, Perth.
Württemberg, Königliche Bibliothek, Stuttgart.

Governmental exchanges for Quebec, Ottawa, Toronto, Winnipeg, and Mexico are not retained at the Institution until an entire box has accumulated, but are promptly dispatched by registered mail as soon as received.

During the year several depositories have been added and reserve sets have been contributed, as follows:

The Commonwealth of Australia, the seat of which is temporarily at Melbourne, was added in December, 1901, and on the 19th of that month 68 boxes were shipped in care of the attorney-general of the Commonwealth.

On September 4, 1901, a shipment was made to the National Library of Ireland at Dublin, consisting of 81 boxes, and the same number was forwarded to the Legislative Library at Quebec on July 26, 1901.

The Legislative Library of Manitoba at Winnipeg was placed on the list of depositories January 16, 1902, but only selections have thus far been provided. It is expected, however, that a more liberal contribution will be made when the additional copies provided under the joint resolution of March 2, 1901, are received from the Public Printer.

Respectfully submitted.

F. W. HODGE,
Acting Curator of Exchanges.

Mr. S. P. LANGLEY,
Secretary of the Smithsonian Institution.

JULY 1, 1902.

Appendix IV.

REPORT OF THE SUPERINTENDENT OF THE NATIONAL ZOOLOGICAL PARK.

Sir: I have the honor to herewith submit the following report relating to the condition and operations of the National Zoological Park for the year ending June 30, 1902:

At the close of that period the approximate value of the property belonging to the park was as follows:

Buildings for animals	$71,000
Buildings for administrative purposes	14,000
Office furniture, books, apparatus, etc	3,900
Machinery, tools, and implements	2,200
Fences and outdoor inclosures	25,000
Roadways, bridges, paths, rustic seats, etc	80,000
Nurseries	1,000
Horses	600
Animals in zoological collection	38,000

A detailed list of the animals in the collection is appended hereto. They may be classified as follows:

	Indigenous.	Foreign.	Domesticated.	Total.
Mammals	337	91	78	506
Birds	125	58	49	232
Reptiles	122	23		145
Total	584	172	127	883

The accessions of animals during the year have been as follows:

Presented	117
Purchased and collected	73
Lent	13
Received from Yellowstone National Park	17
Received in exchange	23
Born in National Zoological Park	69
Captured in National Zoological Park	2
Total	314

Besides these animals about 50 gray squirrels were purchased during the year and set at liberty in the park.

The cost for purchase, collection, and transportation of these accessions has been $3,500. Besides this there has been spent for books, photographs, apparatus, and office furniture the sum of $1,900.

The appropriation for the general service of the park was made in the following terms:

For continuing the construction of roads, walks, bridges, water supply, sewerage and drainage; and for grading, planting, and otherwise improving the grounds;

erecting and repairing buildings and inclosures; care, subsistence, purchase, and transportation of animals; including salaries or compensation of all necessary employees; the purchase of necessary books and periodicals, the printing and publishing of operations, not exceeding one thousand five hundred copies, and general incidental expenses not otherwise provided for, eighty thousand dollars; one-half of which sum shall be paid from the revenues of the District of Columbia and the other half from the Treasury of the United States; and of the sum hereby appropriated five thousand dollars shall be used for continuing the entrance into the Zoological Park from Cathedral avenue and opening driveway into Zoological Park, including necessary grading and removal of earth. (Sundry civil act March 3, 1901.)

Besides the regular cost of maintenance, the following alterations and additions to the buildings and grounds have been defrayed from this appropriation during the year:

The flying cage.—This large cage, begun during the last year, has now been completed and fitted with rockwork, planted with aquatic and other plants, and supplied with running water and pools. About 50 birds are at present in the cage and it is hoped to increase the number considerably next season. The cage forms a very attractive feature of the park. The expenditure from this year's appropriation in connection with it is about $5,000.

Addition to temporary bird house.—There being no suitable place for parrots, of which the collection included a considerable number, a room for them was added to the temporary bird house and divided into five large compartments. Several birds were put in each cage and they have much improved in health and attractiveness since this disposition of them was made. This addition cost $700.

Repairing elephant shed.—Attention has before been called to the dilapidated condition of the structure. It had become so open about the sides that it could not be made warm enough for the animal in cold weather. In the autumn of 1901 a layer of heavy building felt was put on the sides and this was covered with siding, at a cost of $250.

An appropriation of $20,000 was asked for a new house for elephants and other pachyderms, and at the close of the year $10,000 was appropriated for that purpose. This will provide for only a small house, the construction of which will be at once commenced.

Cages for polar and Kodiak bear.—Two large yards for these bears were begun about the close of the year. Each will be about 40 feet square, with secure and comfortable house and a large bathing pool attached. The cages will cost, complete, about $1,800.

Cage for eagles.—Shortly before the close of the year a cage for eagles was begun, 50 feet by 27 feet and 35 feet high. It will contain a pool, a mass of rock, and a large tree on which the birds may perch. The cost will be $1,000.

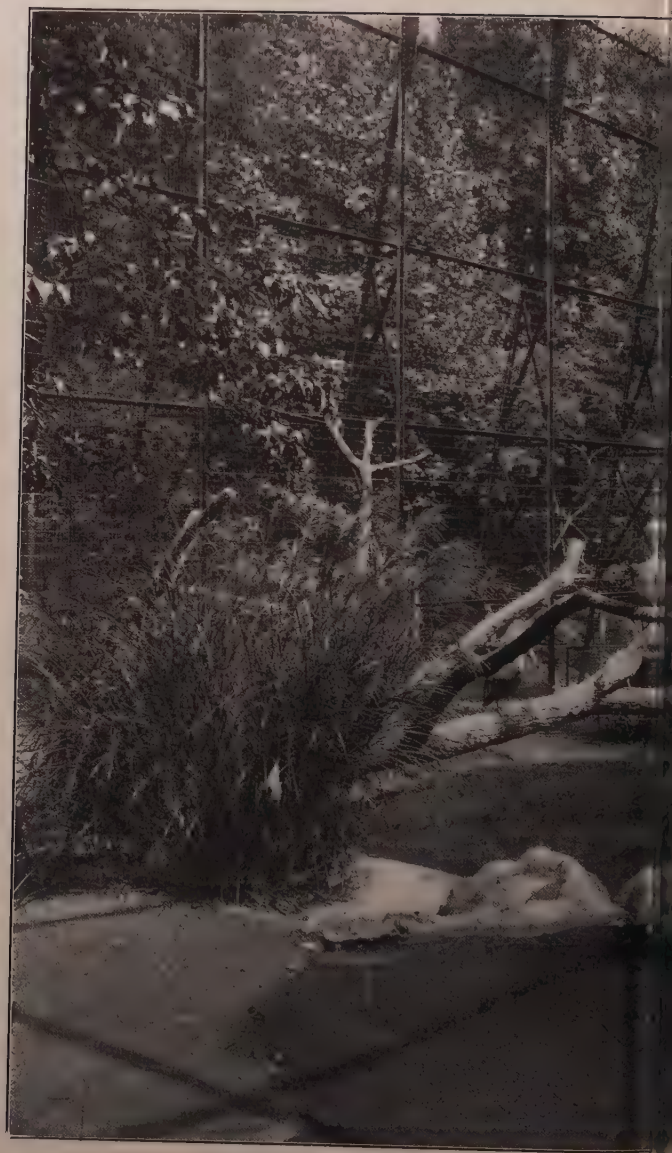
Carnivora house.—The large floor tank for alligators having become decayed and leaky, a new tank was built of concrete. A large case was also constructed in this building for boas and pythons. This installation is not suitable for either the alligators or the snakes, and the space which they occupy is needed for other purposes.

Fountain.—At the Secretary's suggestion a fountain was constructed in front of the carnivora house, at a cost of $350.

Driveway from Cathedral avenue.—A portion of the fill of earth required was made from the appropriation for the previous year; fill was completed and roadway 18 feet wide built, with telford base and top dressing of crushed stone. A small amount of work was also done at the ford on this road. Total cost $5,000, the amount of the special appropriation.

Adams Mill road.—By reason of its very steep grade, this road is difficult to maintain. It became necessary to reshape the steep portion; the macadam was thoroughly loosened, the crown of the road remade, adding considerable new material, and the road finished with a new surface dressing of crushed limestone.

Connecticut avenue entrance.—The roadway on Joliet street between Connecticut avenue and the park entrance was completed by the District on permanent lines, and



FLYING CAGE I



ONAL ZOOLOGICAL PARK.

making it necessary to change the line of the roadway in the park for a distance of about 300 feet.

A walk of crushed stone was constructed at the Adams Mill road entrance to connect with the new concrete walk laid by the District in April of this year. Considerable work was done on other walks and a footbridge was erected to afford convenient access from the east bank of the creek, near the upper ford, to the west bank and the paddocks near by.

Planting was carried on throughout the year. A screen of shrubs and small trees was set about the shop building and many shrubs and vines were planted around the office building as a screen and for ornament.

Observations on flying birds.—The park, though full of interest for the public, is not a place of recreation only, for though one of its primary objects is the instruction and recreation of the people, another—indeed, the very first of all prescribed by Congress—is the advancement of science, and for this latter we must look to experiments in the future for which we have not means to-day. In pursuance of a purely scientific problem, the park has recently procured optical apparatus for determining the interesting problem of the flight of the soaring bird by photographing the great buzzard (*Cathartes aura*) simultaneously from two adjacent temporary wooden towers which have been erected.

The following are the more important accessions to the collection during the year:

Gifts.—Dr. F. W. Goding, United States consul at Newcastle, New South Wales, shipped several lots of animals by sailing vessels to San Francisco (thus securing free transportation). Most of the animals died during the long voyage. A fine specimen of dingo, however, arrived in good condition, and a fine gray kangaroo and brush-tailed opossum were received shortly after the close of the year. Dr. Goding is exceptionally well placed for getting animals, takes active interest, and expects to get valuable specimens. He has been asked to forward future consignments by steamer to shorten the time of voyage.

By E. H. Plumacher, United States consul at Maracaibo, a considerable consignment of animals was forwarded, but several died en route. A monkey and a fine specimen of two-toed sloth were received in good order. Other animals are to be sent soon.

From Perry M. De Leon, United States consul-general at Guyaquil, Ecuador, a fine lot of animals was received, including parrots, a toucan, three monkeys, and several smaller animals. He also forwarded two consignments by sailing vessel, but these died en route.

From Solomon Berliner, United States consul at Teneriffe, two lanzarotte pigeons and two choughs.

From J. H. Starin, New York, six harbor seals.

From Oscar J. Craig, president University of Montana, a very fine beaver.

From Stephen Gheen, Tower, Minn., a pair of Canada lynx.

From August Busck, United States Department of Agriculture, five Cuban boas.

In connection with animals presented by Consul Plumacher, I wish to acknowledge the courtesy of Messrs. Boulton, Bliss & Dallet, of New York, in furnishing free transportation for animals on their Red D Line of steamships from Maracaibo to New York.

From Capt. John L. Young, proprietor of Young's pier, Atlantic City, N. J., a considerable number of fish were obtained for the aquarium. Captain Young also kindly assisted the agent sent by the park to procure specimens.

Yellowstone National Park.—From this source there were received during the year four antelope, five mule deer, five elk, two cinnamon bears, one grizzly bear.

The acting superintendent of the Yellowstone National Park sent word that there was opportunity to capture a grizzly. A steel cage-trap was accordingly constructed in the shops of the National Zoological Park and shipped to the Yellowstone. A

fine specimen was captured in this trap and forwarded to Washington, reaching its destination in good order.

Exchanges.—Several exchanges were effected during the year. Among the animals obtained were the following: From the New York Zoological Park, a very fine male axis deer; from the Zoological Society of London, a young female yak; from Thomas W. Gibson, of the department of crown lands, Ontario, Canada, eight black squirrels; from William Bartels, New York, a female Barbary sheep and a female polar bear.

Births.—The number of births during the year has been quite satisfactory. It is gratifying to note that two beavers were born during the present season.

Purchases.—Under your instructions very special efforts have been made in the last three or four years to procure a Kodiak bear. The animal is by no means exterminated, but has fled to uninhabited, difficult regions, where it can not be obtained except by the expenditure of an inordinate sum of money, whereas it was formerly procurable in relative abundance. A young male was, however, procured during the present year through the cooperation of the Alaska Commercial Company. It was captured on the mainland directly opposite Kodiak Island, and is believed to be the true *Ursus middendorffii*. Efforts are being made to get more through the same agency. Considerable rewards for additional specimens have been offered throughout that region and are still advertised, though so far without results.

After years of effort two bighorn or Rocky Mountain sheep have been procured from western Colorado, one within the present year. It is desirable to explain that the Institution's extreme difficulty in procuring this animal, not at all an unfamiliar one to hunters, arises from the fact that the Institution proceeds scrupulously within the law, which requires a permit from the authorities of the State in each case. This is charily given, in some cases apparently through the opposition of game wardens, who seem to have no sympathy with the Institution's aims. These permits, while only obtained with great difficulty, are given for a brief time and to a single individual. The whole system is apparently designed with a proper purpose to throw obstacles in the way of procuring game by unfit persons. It actually operates to almost absolutely prevent its procurement by the General Government through institutions or persons who are the fit recipients of the game, and as scrupulous in their desire to obey the State laws as the Smithsonian Institution is in its capacity as guardian of the Government interests in the National Zoological Park. Further than this, or indeed as a consequence of the practical refusal of permission under the law, the final effect is that nearly the only animals which are obtainable are those for sale by persons who have taken them in defiance of the law.

Other purchases were a male moose and a pair of Columbian black-tailed deer from the International Forest, Fish, and Game Association, two female pumas from northwestern Wyoming, two young California condors, a female South American tapir (as a mate for the male already in the collection), three red kangaroos, and a carabao, or Indian buffalo, from the Philippine Islands (under recent regulations of the Department of Agriculture, to prevent the introduction of "surra," such animals can not now be imported). A stock of birds was obtained for the flying cage, including a pair of adjutants, six European storks, an ibis, and other birds.

One of the bears procured in Alaska for the park in the summer of 1900, being now old enough for its identity to be determined, is found to be the Yakutat bear, *Ursus dalli*.

Losses of animals.—Two old bull bisons; death probably due to old age; diagnosis gastroenteritis. One California sea-lion, from pneumonia. A male and female moose, from gastroenteritis; received November, 1899, died December, 1901, and March, 1902; in good health until summer of 1901. Great difficulty is still experienced in the care of these great forest animals. Three pronghorn antelopes, including a buck that had been in the park five and a half years. One young elk, killed by an old bull.

From the effects of intestinal parasites: Three Newfoundland caribou, a litter of arctic foxes, one adult fox, and one mule deer. A number of other mule and other deer were affected. These parasites were probably introduced and distributed by prowling dogs. In order to extirpate them, the mule deer were treated and removed to another paddock; their former paddock was then disinfected by burning over the surface of the ground with a surface heater such as is used in repairing asphalt pavements.

Boundary fence.—In making up the estimates for the appropriations for the next year, as for the past several years, the imperative need of a fence was again urged upon Congress. No special appropriation was made, however, but it was understood that the increase in the regular appropriation might be devoted to this purpose if the Secretary saw fit.

Attention has been called in previous reports to the fact that no adequate provision for housing small tropical mammals exists in the park. At present these animals are confined in small cages, which are sometimes placed on the top of others, thus injuring the appearance of the collection. The animals are also deprived of adequate exercise. Their mortality is therefore unnecessarily great. The park receives every year a considerable number of such animals, particularly from the new possessions of the United States, and is very much embarrassed to find room for them. For those at present at hand, not considering any future additions, there is required a space of 140 linear feet of cages. It is recommended that Congress be asked to appropriate a sufficient sum to build a suitable house for tropical mammals where they can be kept in better health and comfort than they are now able to enjoy.

No department of the park attracts more popular interest than the aquarium, and its educational value is certainly very great. The present installation of this collection of salt-water and fresh-water species in a mere temporary shed is, however, so entirely inadequate to its needs that I would urge the construction of a suitable building fitted with permanent tanks, heating and refrigerating apparatus, and open pools.

In accordance with the Secretary's wish to see a larger development given to the salt-water fauna, a concrete tank, covered with a glass roof, was built for the storage of sea water, and the north side of the building will be devoted to this part of the exhibition. A new filter has been provided, and other minor improvements have been made.

Another important need is a reptile house where the great tortoises, crocodiles, alligators, boas, pythons, anacondas and other reptiles belonging to the collection can be exhibited, and where other specimens obtained from time to time can be housed. These reptiles are now placed in the same house with the lions, tigers, and other cats.

The park very much needs an aviary for small terrestial birds. The present bird house is almost entirely occupied by struthious and aquatic birds, the song birds being wholly unrepresented. In connection with such an aviary there should be built a flying-cage of moderate size, with a tunnel of cage work through which the public can walk, surrounded by singing birds flitting about in every direction.

The collection of wolves and foxes has hitherto been kept in a series of temporary pens near the principal animal house. These inclosures are far from satisfactory, as they soon become dilapidated and permit the animals to dig out or break through. New and permanent quarters for these animals should be erected in some suitable part of the park.

The sea-lions and seals now in the park are not provided with proper quarters. As the turbidity of the water in the large pool seriously injured them they have recently been confined in cages built for the bears near the Quarry Road entrance. They have here only very small basins of water and are not able to swim about at all. Houses and a pond of filtered water should be provided for them.

The attendance of visitors at the park has been steadily increasing. At present the average daily number of visitors is larger than ever before, and on several occasions 30,000 persons have been in the park in a single day. This increase in attendance

further emphasizes the need for more efficient restaurant facilities. At present there is no suitable restaurant, only an open pavilion where candy, cakes, and light beverages are sold. As the park is at a considerable distance from the city, the absence of a properly equipped restaurant is a great inconvenience to those wishing to spend the day in it, particularly if they are accompanied by children. The erection of a public-comfort building especially equipped for ladies and children, and with a restaurant attached, is therefore very desirable.

It would be much more satisfactory as well as less expensive if sufficient appropriations could be made to provide permanent buildings as rapidly as they are required by the public needs and the growth of the collection. At present a considerable part of the appropriation has to be spent each year in repairing temporary structures. The park has now been in operation long enough to safely determine where permanent improvements should be placed.

The principal object for which the park was originally instituted was the preservation of our national game, especially that which is becoming extinct. This has been represented to Congress, but as yet no special provision has been made for it. According to your recommendation an appropriation will again be asked for collecting and preserving some of the great land and marine specimens of our western territory now rapidly disappearing. Experience has abundantly proved that such wild creatures, unaccustomed as they are to the sight of man, can not properly be transported immediately after capture, as they are likely to seriously injure themselves or even to die of fright if some means are not taken to gentle them or accustom them to being handled. I can therefore entirely agree to the value of the method you have proposed of establishing some small station or stations in Alaska where there are yet found specimens of the Kodiak bear, the great moose, the walrus, the fur seal, and possibly other large creatures. They could there be confined and kept amidst familiar scenes and be fed upon their natural food while becoming more accustomed to the sight of man and more tractable. The expenditure for such stations would be slight.

I have already mentioned that after years of effort the park has at last procured one Kodiak bear cub. Bears as a rule do not breed freely in captivity, but it is most desirable to try the experiment, under such favorable conditions as the park may afford, and I hope that more animals of this species may be obtained.

I close with a list of the animals of the park on June 30, 1902, and with a reiteration of the statement that the park is nevertheless not filling its principal function until it can maintain and preserve for posterity the most important specimens of the great vanishing fauna of this country, and particularly of Alaska.

Animals in National Zoological Park, June 30, 1902.

Name.	Number.	Name.	Number.
MAMMALS.		MAMMALS—continued.	
North American species.		*North American species*—Continued.	
American bison (*Bison americanus*)	9	American elk (*Cervus canadensis*)	22
Prong-horn antelope (*Antilocapra americana*)	4	Woodland caribou (*Rangifer caribou*)	1
Rocky Mountain sheep (*Ovis canadensis*)	2	Newfoundland caribou (*Rangifer terrænovæ*)	1
Virginia deer (*Odocoileus virginianus*)	10	Moose (*Alces americanus*)	1
Columbia black-tailed deer (*Odocoileus columbianus*)	1	Collared peccary (*Tayassu angulatum*)	3
Mule deer (*Odocoileus hemionus*)	9	Puma (*Felis concolor*)	3
Cuban deer (*Odocoileus* sp.)	1	Ocelot (*Felis pardalis*)	5
		Yaguarundi (*Felis yagouaroundi*)	2
		Eyra (*Felis eyra*)	1

Animals in National Zoological Park, June 30, 1902—Continued.

Name.	Number.
MAMMALS—continued.	
North American species—Continued.	
Bay lynx (*Lynx rufus*)	2
Spotted lynx (*Lynx rufus maculatus*)	2
Florida lynx (*Lynx rufus floridanus*)	1
Bailey's lynx (*Lynx baileyi*)	2
Canada lynx (*Lynx canadensis*)	1
Gray wolf (*Canis griseus*)	10
Black wolf (*Canis griseus*)	3
Coyote (*Canis latrans*)	6
Red fox (*Vulpes fulvus*)	6
Cross fox (*Vulpes fulvus*)	1
Arctic fox (*Vulpes lagopus*)	12
Swift fox (*Vulpes velox*)	6
Gray fox (*Urocyon cinereoargenteus*)	4
North American otter (*Lutra hudsonica*)	2
American badger (*Taxidea taxus*)	3
Kinkajou (*Totos caudivolvulus*)	2
American civet cat (*Bassariscus astutus*)	1
Gray coatimundi (*Nasua narica*)	1
Raccoon (*Procyon lotor*)	27
Black bear (*Ursus americanus*)	6
Cinnamon bear (*Ursus americanus*)	4
Grizzly bear (*Ursus horribilis*)	3
Yakutat bear (*Ursus dalli*)	1
Kodiak bear (*Ursus middendorffi*)	1
Polar bear (*Thalarctos maritimus*)	2
California sea lion (*Zalophus californianus*)	1
Steller's sea lion (*Eumetopias stelleri*)	1
Harbor seal (*Phoca vitulina*)	6
Common pocket gopher (*Geomys bursarius*)	2
California pocket gopher (*Thomomys bottæ*)	2
Mountain pack-rat (*Neotoma cinerea*)	2
American beaver (*Castor canadensis*)	8
Hutia-conga (*Capromys pilorides*)	9
Woodchuck (*Arctomys monax*)	1
Prairie dog (*Cynomys ludovicianus*)	37
Southern fox squirrel (*Sciurus niger*)	3
Western fox squirrel (*Sciurus ludovicianus*)	8
Gray squirrel (*Sciurus carolinensis*)	23
Black squirrel (*Sciurus carolinensis*)	10
Mountain chipmunk (*Tamias speciosus*)	18
Beechey's ground squirrel (*Spermophilus grammurus beecheyi*)	1
Antelope chipmunk (*Spermophilus leucurus*)	2
Northern varying hare (*Lepus americanus*)	9
Peba armadillo (*Tatu novemcinctum*)	6
Opossum (*Didelphys marsupialis*)	4

Name.	Number.
MAMMALS—continued.	
Domesticated and foreign species.	
Grivet monkey (*Cercopithecus griseoviridis*)	1
Macaque monkey (*Macacus cynomolgus*)	4
Bonnet monkey (*Macacus sinicus*)	1
Pig-tailed monkey (*Macacus nemestrinus*)	3
Japanese monkey (*Macacus speciosus*)	1
Black ape (*Cynopithecus niger*)	1
Black-handed spider monkey (*Ateles geoffroyi*)	1
Apella monkey (*Cebus apella*)	1
Capuchin (*Cebus capucinus*)	4
Ruffed lemur (*Lemur varius*)	2
Lion (*Felis leo*)	5
Tiger (*Felis tigris*)	2
Leopard (*Felis pardus*)	2
Spotted hyena (*Hyæna crocuta*)	1
Striped hyena (*Hyæna striata*)	2
Wolf hound	2
St. Bernard dog	1
Pointer	1
Bedlington terrier	1
Smooth-coated fox terrier	3
Wire-haired fox terrier	1
Eskimo dog	2
Bear cat (*Arctictis binturong*)	1
Mongoose (*Herpestes mungo*)	1
Tayra (*Galictis barbara*)	1
Red coatimundi (*Nasua rufa*)	2
Crab-eating raccoon (*Procyon cancrivora*)	2
Japanese bear (*Ursus japonicus*)	1
Sun bear (*Ursus malayanus*)	3
Sloth bear (*Melursus labiatus*)	1
European hedgehog (*Erinaceus europæus*)	1
Wild boar (*Sus scrofa*)	2
Solid-hoofed pig (*Sus scrofa*)	1
White-lipped peccary (*Tayassu albirostris*)	1
Zebu (*Bos indicus*)	5
Carabao (*Bos bubalus*)	1
Yak (*Poëphagus grunniens*)	2
Barbary sheep (*Ovis tragelaphus*)	2
Common goat (*Capra hircus*)	9
Cashmere goat (*Capra hircus*)	4
Nilgau (*Boselaphus tragocamelus*)	2
Indian antelope (*Antilope cervicapra*)	2
Sambur deer (*Cervus aristotelis*)	1
Philippine deer (*Cervus philippinus*)	1
Axis deer (*Cervus axis*)	1
Fallow deer (*Dama vulgaris*)	4

Animals in National Zoological Park, June 30, 1902—Continued.

Name.	Number.
MAMMALS—continued.	
Domesticated and foreign species—C't'd.	
Common camel (*Camelus dromedarius*)	2
Bactrian camel (*Camelus bactrianus*)	1
Llama (*Auchenia glama*)	5
South American tapir (*Tapirus americanus*)	2
Donkey (*Equus asinus*)	1
Indian elephant (*Elephas indicus*)	1
Ecuador squirrel (*Sciurus* sp)	1
Crested agouti (*Dasyprocta cristata*)	1
Mexican agouti (*Dasyprocta mexicana*)	2
Hairy-rumped agouti (*Dasyprocta prymnolopha*)	1
Azara's agouti (*Dasyprocta azaræ*)	3
Acouchy (*Dasyprocta acouchy*)	3
Golden agouti (*Dasyprocta aguti*)	2
Albino rat (*Mus rattus*)	5
Crested porcupine (*Hystrix cristata*)	3
Guinea pig (*Cavia porcellus*)	14
English rabbit (*Lepus cuniculus*)	17
Two-toed sloth (*Cholœpus didactylus*)	1
Six-banded armadillo (*Dasypus sexcinctus*)	1
Great gray kangaroo (*Macropus giganteus*)	3
Red kangaroo (*Macropus rufus*)	3
Brush-tailed rock kangaroo (*Petrogale penicillata*)	4
BIRDS.	
Road runner (*Geococcyx californianus*)	1
Toucan (*Ramphastos tocard*)	1
Sulphur-crested cockatoo (*Cacatua galerita*)	2
Leadbeater's cockatoo (*Cacatua leadbeateri*)	1
Roseate cockatoo (*Cacatua roseicapilla*)	4
Yellow and blue macaw (*Ara ararauna*)	3
Red and yellow and blue macaw (*Ara macao*)	2
Red and blue macaw (*Ara chloroptera*)	1
Hyacinthine macaw (*Anodorhynchus hyacinthinus*)	1
Chattering lory (*Lorius garrulus*)	2
Green paroquet (*Conurus* sp.)	2
Carolina paroquet (*Conurus carolinensis*)	3
Yellow-naped amazon (*Amazona auropalliata*)	7
White-fronted amazon (*Amazona leucocephala*)	3
Double yellow head (*Amazona oratrix*)	3
Mealy amazona (*Amazona farinosa*)	1

Name.	Number.
BIRDS—continued.	
Great horned owl (*Bubo virginianus*)	11
Barred owl (*Syrnium nebulosum*)	2
Barn owl (*Strix pratincola*)	2
Bald eagle (*Haliæetus leucocephalus*)	12
Harpy eagle (*Thrasaëtus harpyia*)	1
Golden eagle (*Aquila chrysaëtos*)	3
Crowned hawk eagle (*Spizaëtus coronatus*)	1
Red-tailed hawk (*Buteo borealis*)	2
California condor (*Gymnogyps californianus*)	3
Turkey vulture (*Cathartes aura*)	6
Black vulture (*Catharista atrata*)	1
King vulture (*Gypagus papa*)	1
Lanzarotte pigeon (*Columba livia*)	3
Ring dove (*Columba palumbus*)	3
Nicobar pigeon (*Calœnas nicobarica*)	1
Chachalaca (*Ortalis vetula maccallii*)	2
Red-tailed guan (*Ortalis ruficauda*)	1
Daubenton's curassow (*Crax daubentoni*)	4
Lesser razor-billed curassow (*Mitua tomentosa*)	1
Pea fowl (*Pavo cristatus*)	27
Valley partridge (*Callipepla californica vallicola*)	2
Mountain partridge (*Oreortyx pictus*)	1
Sandhill crane (*Grus mexicana*)	3
Whooping crane (*Grus americana*)	1
Green heron (*Ardea virescens*)	2
Little blue heron (*Ardea cœrulca*)	2
Great blue heron (*Ardea herodias*)	8
Black-crowned night heron (*Nycticorax nycticorax nævius*)	10
Boatbill (*Cochlearius cochlearius*)	1
White stork (*Ciconia alba*)	4
Black stork (*Ciconia nigra*)	2
Marabou stork (*Leptoptilus crumenifcrus*)	2
White ibis (*Guara alba*)	2
Wood ibis (*Tantalus loculator*)	6
Trumpeter swan (*Olor buccinator*)	5
Whistling swan (*Olor columbianus*)	1
Mute swan (*Cygnus gibbus*)	2
Brant (*Branta bernicla*)	2
Canada goose (*Branta canadensis*)	6
Hutchin's goose (*Branta canadensis hutchinsii*)	1
Chinese goose (*Anser cygnoides*)	2
Greater snow goose (*Chen hyperborea nivalis*)	2
Wood duck (*Aix sponsa*)	4
Mandarin duck (*Dendronessa galericulata*)	8

Animals in National Zoological Park, June 30, 1902—Continued.

Name.	Number.
BIRDS—continued.	
Pintail (*Dafila acuta*)	1
Pekin duck (*Anas* sp.)	2
Mallard duck (*Anas boschas*)	2
Common duck (*Anas boschas*)	2
American tree duck (*Dendrocygna discolor*)	1
American white pelican (*Pelecanus erythrorhynchos*)	6
Brown pelican (*Pelecanus fuscus*)	5
Florida cormorant (*Phalacrocorax dilophus floridanus*)	3
Snake bird (*Anhinga anhinga*)	2
Common rhea (*Rhea americana*)	1
Cassowary (*Casuarius australis*)	3
Emu (*Dromæus novæ-hollandiæ*)	1
REPTILES.	
Alligator (*Alligator mississippiensis*)	15
American crocodile (*Crocodilus americanus*)	2
Painted turtle (*Chrysemys picta*)	6
Musk turtle (*Aromochelys odorata*)	2
Mud turtle (*Cinosternum pennsylvanicum*)	5
Terrapin (*Pseudemys* sp.)	1
Gopher turtle (*Xerobates polyphemus*)	1
Box tortoise (*Cistudo carolina*)	2
Three-toed box tortoise (*Cistudo triunguis*)	6

Name.	Number.
REPTILES—continued.	
Painted box tortoise (*Cistudo ornata*)	5
Duncan Island tortoise (*Testudo ephippium*)	2
Albemarle Island tortoise (*Testudo vicina*)	2
Brazilian tortoise (*Testudo tabulata*)	4
Comb lizard (*Ctenosaura* sp.)	1
Alligator lizard (*Sceloporus* sp.)	1
Horned lizard (*Phrynosoma cornutum*)	21
Glass snake (*Ophiosaurus ventralis*)	1
Gila monster (*Heloderma suspectum*)	5
Diamond rattlesnake (*Crotalus adamanteus*)	2
Copperhead (*Ancistrodon contortrix*)	4
Water moccasin (*Ancistrodon piscivorus*)	3
Cuban tree boa (*Epicrates angulifer*)	5
Common boa (*Boa constrictor*)	12
Anaconda (*Eunectes murinus*)	2
Bull snake (*Pityophis sayi sayi*)	9
Black snake (*Bascanium constrictor*)	9
King snake (*Ophibolus getulus*)	4
Milk snake (*Ophibolus doliatus*)	1
Garter snake (*Eutænia sirtalis*)	2
Water snake (*Natrix sipedon*)	3
Hog-nosed snake (*Heterodon platyrhinus*)	1
Gopher snake (*Spilotes corais couperii*)	6

List of accessions for the fiscal year ending June 30, 1902.

ANIMALS PRESENTED.

Name.	Donor.	Number.
Cebus monkey	E. H. Plumacher, United States consul, Maracaibo, Venezuela.	1
White-throated capuchin	Mrs. M. T. Battle, Rocky Mount, N. C.	1
Do	Perry M. de Leon, United States consul-general, Guayaquil, Ecuador.	1
Canada lynx	Stephen Gheen, Tower, Minn	2
Cross fox	N. E. Skinner, Bangor, Me	1
Gray fox	Mrs. G. W. Gilmer, Howardsville, Va	1
Mongoose	S. D. Nixon, Baltimore, Md	1
Raccoon	H. Burrows, Washington, D. C	1
Do	C. H. Ehrhardt, Washington, D. C	1
Harbor seal	John H. Starin, Glen Island, N. Y	6
Common goat	E. G. Seggers, Washington, D. C	1
Donkey	Mrs. L. O. Leary, Washington, D. C	1
Black squirrel	Miss M. C. H. Pickett, Marshville, Ontario	2
Ecuador squirrel	Perry M. de Leon, United States consul-general, Guayaquil, Ecuador.	1
Prairie dog	Dr. Joseph Price, Philadelphia, Pa	4

List of accessions for the fiscal year ending June 30, 1902—Continued.

ANIMALS PRESENTED—Continued.

Name.	Donor.	Number.
American beaver	Oscar J. Craig, president University of Montana, Missoula, Mont.	1
Hutia-conga	Lawrence O. Wilkins, Washington, D. C	4
Mountain pack rat	James Fullerton, Red Lodge, Mont	3
Azara's agouti	Perry M. de Leon, United States consul-general, Guayaquil, Ecuador.	1
Canada porcupine	G. Dewitt, Alexandria Bay, N. Y	1
Two-toed sloth	E. H. Plumacher, United States consul, Maracaibo, Venezuela.	1
Nine-banded armadillo	F. Hardman, San Antonio, Tex	2
Opossum	The President of the United States	4
Do	J. H. Cranford, Washington, D. C	1
Common crow	P. H. Willis, Washington, D. C	1
Black-headed jay	James Fullerton, Red Lodge, Mont	1
Chough	Solomon Berliner, United States consul, Teneriffe, Canary Islands.	2
Toucan	Perry M. de Leon, United States consul-general, Guayaquil, Ecuador.	1
Sulphur-crested cockatoo	Mrs. A. L. Barber, Washington, D. C	1
Yellow-naped amazon	Perry M. de Leon, United States consul-general, Guyaquil, Ecuador.	2
Barred owl	Major J. S. Turner, Washington, D. C	1
Sparrow hawk	Frank Fabri, Lombard, Ill	1
Lanzarotte pigeon	Solomon Berliner, United States consul, Teneriffe, Canary Islands.	3
Nicobar pigeon	D. A. Barnes, Washington, D. C	1
Daubenton's curassow	Hon. Charles H. Allen, governor of Porto Rico, Lowell, Mass.	1
Great blue heron	J. L. Murphy, Washington, D. C	1
Little blue heron	Perry M. de Leon, United States consul-general, Guyaquil, Ecuador.	1
Black-crowned night heron	Donor unknown	4
Wood ibis	A. M. Nicholson, Orlando, Fla	3
Greater snow goose	Dr. A. M. Reed, Washington, D. C	2
Alligator	Mrs. A. Lancaster, Washington, D. C	1
Do	Dr. C. B. Campbell, Washington, D. C	1
Horned lizard	E. Meyenberg, Pecos, Tex	21
Iguana	Donor unknown (through Major F. von Schrader, U. S. A.)	1
Mexican comb-lizard	L. M. O'Leary, Washington, D. C	1
Gila monster	Dr. M. M. Crocker, Lordsburg, N. Mex	1
Banded rattlesnake	J. D. Powell, Harpers Ferry, W. Va	2
Do	George W. Colles, Washington, D. C	1
Do	G. Pulliam, Harrodsburg, Ky	1
Water moccasin	A. M. Nicholson, Orlando, Fla	2
Copperhead	C. H. Kreh, Frederick, Md	2
Do	J. G. Dudley, Friendship, N. C	1
Tree boa	Donor unknown (collected in Porto Rico)	1
Cuban tree boa	August Busck, Washington, D. C	5
Black snake	H. M. Sandford, Washington, D. C	1
Do	G. Pulliam, Harrodsburg, Ky	1
King snake	Dr. I. W. Blackburn, St. Elizabeth, D. C	1
Do	F. McGrath, Washington, D. C	1
Garter snake	United States Patent Office	1
Do	Donor unknown	1
Water snake	United States Patent Office	1

List of accessions for the fiscal year ending June 30, 1902—Continued.

ANIMALS LENT.

Name.	Donor.	Number.
Black-handed spider monkey.	Mrs. Nathaniel Page, Chevy Chase, Md	1
Do	M. Magruder, Washington, D. C	1
Cebus	Perry M. de Leon, United States consul-general, Guyaquil, Ecuador.	2
Yellow and blue macaw	Hon. W. B. Ridgeley, Comptroller of the Treasury	1
Hyacinthine macaw	Miss Ethel Roosevelt, Washington, D. C	1
Chattering lory	Capt. H. G. Lyon, U. S. Army	2
Yellow-naped amazon	Mrs. A. B. Williams, Washington, D. C	1
Do	Perry M. de Leon, United States consul-general, Guyaquil, Ecuador.	4

ANIMALS RECEIVED IN EXCHANGE.

Polar bear	William Bartels, New York	1
Striped hyena	Frank C. Bostock, Boston, Mass	2
Yak	The Zoological Society, London, England	1
Aoudad, or Barbary sheep	William Bartels, New York	2
Common goat	E. S. Schmid, Washington, D. C	3
Axis deer	New York Zoological Park, New York	1
Southern fox squirrel	E. S. Schmid, Washington, D. C	3
Black squirrel	Thomas W. Gibson, superintendent for parks, department of Crown lands, Ontario, Canada.	8
Nicobar pigeon	William Bartels, New York	2

ANIMALS PURCHASED AND COLLECTED.

Name.	Number.	Name.	Number.
Pig-tailed monkey (*Macacus nemestrinus*)	2	Fallow deer (*Dama vulgaris*)	2
Japanese monkey (*Macacus speciosus*)	1	Moose (*Alces americanus*)	1
Ruffed lemur (*Lemur varius*)	2	South American tapir (*Tapirus americanus*)	1
Puma (*Felis concolor*)	2	American beaver (*Castor canadensis*)	1
Yaguarundi cat (*Felis yagouaroundi*)	2	Nine-banded armadillo (*Tatu novemcinctum*)	2
Eyra cat (*Felis eyra*)	1	Red kangaroo (*Macropus rufus*)	3
Bay lynx (*Lynx rufus*)	4	Golden eagle (*Aquila chrysaëtos*)	1
Florida lynx (*Lynx rufus floridanus*)	2	California condor (*Gymnogyps californianus*)	2
Bailey's lynx (*Lynx baileyi*)	2	White stork (*Ciconia alba*)	4
Striped hyena (*Hyæna striata*)	1	Black stork (*Ciconia nigra*)	2
Gray wolf (*Canis griseus*)	2	Marabou stork (*Leptoptilus crumenifcrus*)	2
Bear cat (*Arctictis binturong*)	1	Wood ibis (*Tantalus loculator*)	4
Kodiak bear (*Ursus middendorffi*)	1	Trumpeter swan (*Olor buccinator*)	2
Japanese bear (*Ursus japonicus*)	1	Wood duck (*Aix sponsa*)	4
Sun bear (*Ursus malayanus*)	2	Cassowary (*Casuarius australis*)	1
Collared peccary (*Tayassu angulatum*)	3	Diamond rattlesnake (*Crotalus adamanteus*)	1
Carabao (*Bos bubalus*)	1	Gopher snake (*Spilotes corais couperii*)	6
Rocky Mountain sheep (*Ovis canadensis*)	1		
Columbia black-tailed deer (*Odocoileus columbianus*)	2		
Axis deer (*Cervus axis*)	1		

List of accessions for the fiscal year ending June 30, 1902—Continued.

ANIMALS BORN IN THE NATIONAL ZOOLOGICAL PARK.

Name.	Number.	Name.	Number
Lion (*Felis leo*)	2	Prairie dog (*Cynomys ludovicianus*)	
Gray wolf (*Canis griseus*)	4	American beaver (*Castor canadensis*)	
Arctic fox (*Vulpes lagopus*)	9	Hutia-conga (*Capromys pilorides*)	
Virginia deer (*Odocoilcus virginianus*)	6	Acouchy (*Dasyprocta acouchy*)	
Elk (*Cervus canadensis*)	5	Brush-tailed rock kangaroo (*Petrogale penicillata*)	
Fallow deer (*Dama vulgaris*)	1	Bull snake (*Pityophis sayi sayi*)	
Llama (*Auchenia glama*)	1		

ANIMALS CAPTURED IN THE NATIONAL ZOOLOGICAL PARK.

Name.	Numbe
Raccoon (*Procyon lotor*)	

ANIMALS RECEIVED FROM THE YELLOWSTONE NATIONAL PARK.

Grizzly bear (*Ursus horribilis*)
Cinnamon bear (*Ursus americanus*)
Prong-horn antelope (*Antilocapra americana*)
Mule deer (*Odocoileus hemionus*)
Elk (*Cervus canadensis*)

SUMMARY.

Animals on hand July 1, 1901	
Accessions during the year	
Total	1,
Deduct loss (by exchange, death, and returning of animals)	
On hand June 30, 1902	

Respectfully submitted.

FRANK BAKER, *Superintendent.*

Mr. S. P. LANGLEY,
Secretary of the Smithsonian Institution.

Appendix V.

REPORT OF THE WORK OF THE ASTROPHYSICAL OBSERVATORY FOR THE YEAR ENDING JUNE 30, 1902.

Sir: The kinds and amounts of the Observatory property are approximately as follows:

Buildings	$6,300
Apparatus	33,300
Library and records	6,000
Total	45,600

During the past year the acquisitions of property of the kind just enumerated have been as follows:

(a) *Apparatus.*—Astronomical and physical apparatus has been purchased at an expenditure of $2,000.

(b) *Library and records.*—The library has been enlarged by the addition of periodicals and books of reference at an expenditure of $200. Books and periodicals have been bound at an expenditure of $250. Total for library, $450.

The observatory inclosure, shown in Plates VI, VII, has been enlarged by the addition of 10 feet along its northern end so as to be now 155 by 77 and to include nearly 12,000 square feet, as against 11,000 square feet formerly. The photographic building has been removed from a position west to a position north of the siderostat, and the buildings and fence have been repainted. These alterations and repairs have been made at an expenditure of $400.

No losses of property have occurred.

The Work of the Observatory.

For convenience, the work of the Observatory will be described under the following headings:

1. Publications and miscellaneous work.
2. Progress of investigations.

(1) *Publications and miscellaneous work.*

In accordance with a resolution of the Senate of the United States,[a] a report was submitted by you at the meeting of Congress in December, showing the appropriations expended, results reached, and present condition of the work of the Astrophysical Observatory. This report consisted of a brief statement of the foundation, aims, results, and present condition of the Observatory; a copy of Volume I of its Annals; a preliminary report of its eclipse expedition of 1900; and several statements[b] by eminent foreign and domestic men of science, giving their views of the

[a] Senate resolution of February 25, 1901.

[b] As indicating the nature of these statements, I here give extracts from two of them:

"I can not deny myself the pleasure of congratulating you on the accomplishment of this vast and important labor. When I think of what it must all have been, I am lost in admiration at the work."—Sir G. G. Stokes.

"To anyone who is conversant with the astronomical work done in recent years it seems wholly unnecessary to testify to the immense value of the work done at the

merits of the Observatory and its works. This report was referred in the Senate to the Committee on the Library and ordered to be printed with all its inclosures. It therefore became necessary to supply some new copies of illustrations for the engravers, and opportunity was offered to correct a number of errors discovered in Volume I of the Annals, so that this new edition, forming a part of Senate Document No. 20, is considerably improved. The preparation of the first drafts for the report, the preparation of new illustrations, and the reading of proofs naturally occupied considerable time of the Observatory staff. Several hundred copies of this edition of the Annals were secured for the Observatory, and thus it will be possible to supply a limited number to those who may from time to time make request for them.

Of the numerous inquiries addressed to the Institution by correspondents all over this country and the world, many relating to astronomy, physics, and chemistry are referred to this Observatory for answer, and thus an amount of time by no means trifling is spent on work of no immediate concern to the Observatory researches. However, the search for the information asked for so frequently leads to obtaining knowledge of value in our own work, that it is on the whole, perhaps, time well spent, independent of considerations of the convenience of the Institution's correspondents.

(2) *Progress of investigations.*

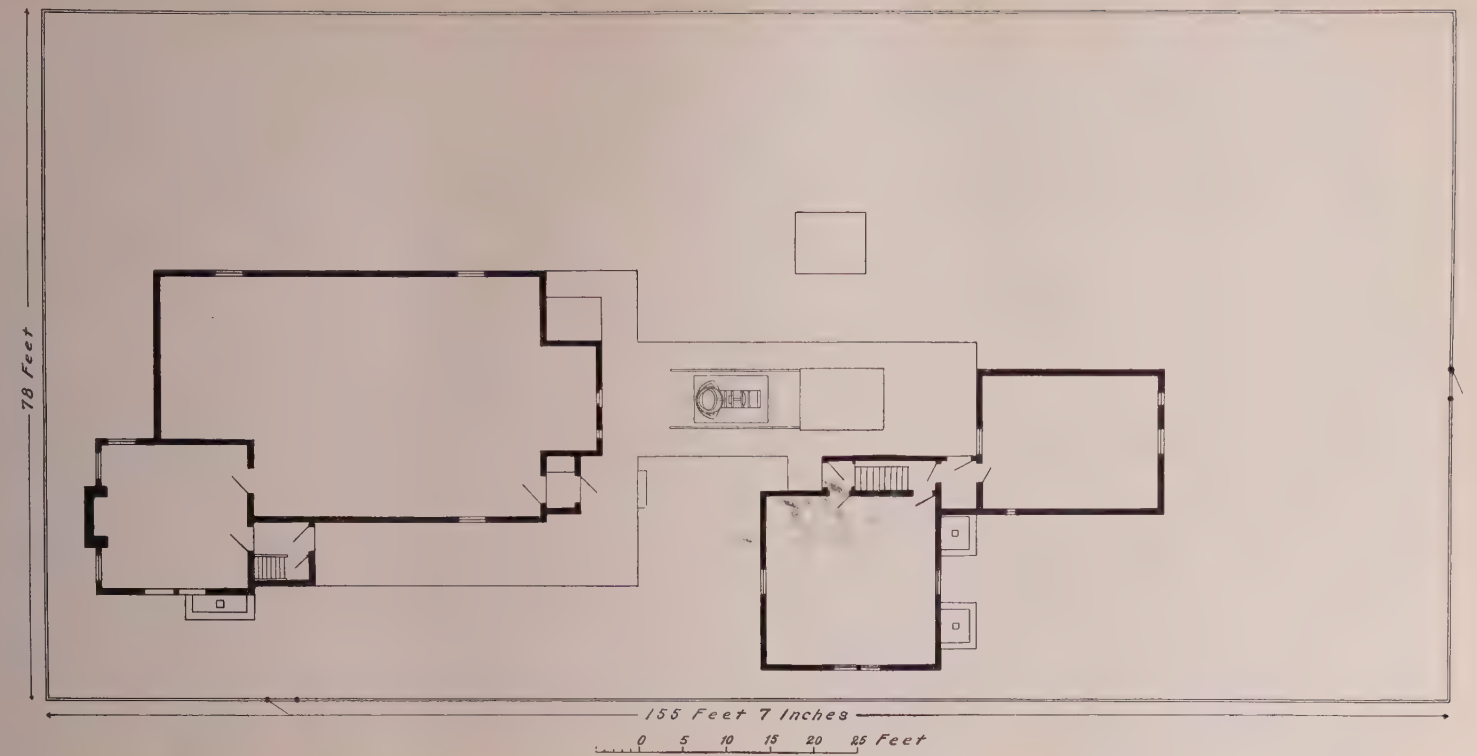
The solar radiation; its total amount and its absorption.—You showed long since that ordinary actinometry, or measures confined to the investigations of white light, can never furnish trustworthy data in relation to the output of the sun, since the absorption of our air is so different for different wave lengths that it is only by going further and examining the spectrum in detail that satisfactory results are obtainable. This kind of energy spectrum work has been taken up very extensively here in the past year.

The solar energy spectrum.—The early work of this Observatory described in Volume 1 of its Annals was chiefly concerned with the minute absorption bands in the infrared solar spectrum. As all readers of the Annals are aware, automatic prismatic energy curves were made by the aid of the bolographic process, and such inflections of these curves as were found not accidental in their origin corresponded to the so-called Fraunhofer lines of the visible spectrum. Less attention was paid to the whole height of these curves at their various parts than to these numerous small variations in height. Still, a chapter of the Annals was devoted to the inferences relating to the absorption of our atmosphere which could be drawn from the data relating to secular variations in the general form of the curves then available. But since the curves were taken at a slow speed to allow full time for recording the small inflections, the total heights were less comparable, owing to possible changes in the transparency of the air, the altitude of the sun, and the behavior of the apparatus which might intervene between start and close of a curve.

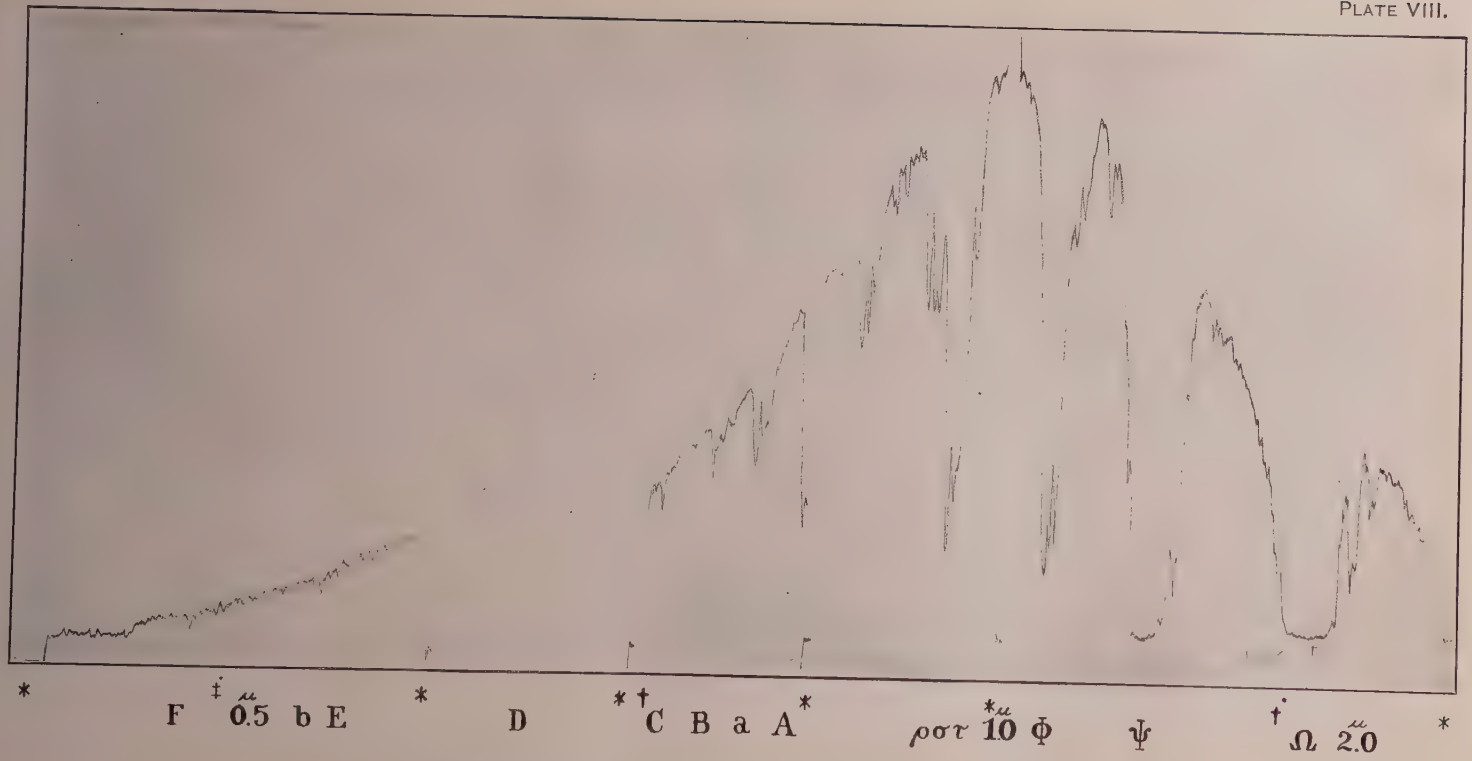
NEW WORK.

The absorption of the atmosphere and of the solar envelope.—This present year care has been taken to obtain energy curves whose heights shall be comparable. It was the purpose of this work to study the general absorption of the sun's envelope, the general absorption of the earth's atmosphere, and the changes in the selective absorption of water vapor in the latter. It is the further object toward which these studies

Astrophysical Observatory under your superintendence. The bolometer, which science owes to your inventive resource, is one of the boldest and most original instruments ever devised for scientific research. It permits the exploration of a field which is entirely closed to any other means of investigation. The many results which you have obtained with this instrument are deemed by all astronomers of the very highest importance in the study of those parts of the spectrum concerning which we should otherwise have remained in ignorance."—Sir ROBERT S. BALL.



GROUND PLAN OF ASTROPHYSICAL OBSERVATORY AND INCLOSURE AS EXISTING JUNE 1, 1902.



SOLAR ENERGY SPECTRUM CURVE TAKEN BY BOLOGRAPHIC APPARATUS IN 15 MINUTES.

* Beam cut off by shutter at these points to give datum marks; † slit enlarged.

tend to see if the sun is constant or variable in its output of radiation. While the results of the past year indicate possibility of considerable ultimate success in this final object, it may probably prove that the situation of this Observatory is unsuitable to the most exact studies of this kind, owing to the great and variable absorption of the air column above it, as well, of course, as to the ground tremors inherent in its present site, surrounded by the traffic of city streets. It seems certain, however, that valuable contributions to the methods of study to be adopted in work at more favorably situated stations, and to the knowledge of terrestrial absorption, can be made here.

Alterations of the apparatus.—For the sake of accuracy in the height of the curves, the speed of taking energy curves has been much increased. Thus we now customarily adopt the speed ratios 2 centimeters of plate and 20 minutes of arc of spectrum in 1 minute of time, while the ratio 1 cm. = 1′ = 1m. was the standard one adopted for the detailed study of the infra-red spectrum. At the present speed the spectrum between wave lengths 0.45 μ in the blue and 2.5 μ in the infra-red is passed over in fifteen minutes. Such a spectrum energy curve is shown in Plate VIII. At this fast speed much less opportunity offers for "drift," alteration of sensitiveness of the galvanometer, and, what is far more common, for clouds or haze to diminish the accuracy of the work. In order to keep the behavior of the apparatus as constant as possible and to get the best possible detail at this rapid speed, the great glass prism has been employed instead of rock salt, thus limiting the research to wave lengths less than 3 μ. But this includes nearly all the solar radiation which reaches the sea level. To avoid extra reflecting and absorbing surfaces as far as practicable, a single mirror is used for collimation of the spectroscope in place of the two employed formerly when great detail was sought, and the bolometer case is used open at the end, although a slight amount of accidental disturbance of the record is involved on windy days. In the interest of the greatest detail practicable at the fast speed, it was most desirable to shorten the time of swing of the galvanometer. A new galvanometer of most approved design has been constructed and has been in use since December, at an average time of single swing of 1.5 seconds. This type of galvanometer is in some respects, I think, new and worth a brief description, which will be found on a later page. To avoid errors from differences of diffraction from the edges of the slit, the slit width has been maintained unaltered at 0.25 mm., subtending 10.5 seconds of arc in the spectrum. Its height, 5 centimeters, has been virtually reduced to 2 centimeters in the infra-red portion of the spectrum by the expedient of interposing across it at the proper time a brass grill-shaped diaphragm, which, being fixed upon pivot bearings on the slit mounting, always occupies the same place when interposed before the slit. The factor of this diaphragm can be measured by the aid of data found on each curve, but the results are constant within the limits of measurement. Bolometer No. 20, of 0.08 millimeter width and subtending 10 seconds of arc, has been used for the entire year. This bolometer has been in use nearly all the time since it was made in 1896, and always with great freedom from drift and other disturbance. Soon after my return from Sumatra I suggested, and you caused to be constructed at the Observatory shop, a more improved type of mechanical rheostat for the bolometer, which has been used since with great satisfaction. Drift of the galvanometer spot now rarely reaches 4 centimeters in a day, and it is rarely in excess of 2 millimeters upon an energy curve taken in fifteen minutes. So firm is confidence in the behavior of the bolometer that the unshunted galvanometer is left in connection with the circuit weeks at a time. No rebalancing of the circuit is required for a month at a time. One can now prepare for bolographic work one day and the next merely start the siderostat and the driving clock with practical certainty of securing a good bolograph.

The absorption of the apparatus.—In order to know the true distribution of the radiations throughout the spectrum, it has been necessary to determine the absorption of the spectroscope. As mirror surfaces deteriorate, this has to be done not

infrequently. The procedure adopted has given the absolute loss by reflection at the siderostat mirror for all wave lengths, and the relative loss for the several wave lengths in the remainder of the apparatus. Without here detailing the procedure at great length, it is sufficient to say that the operation consists of two parts. First a second spectroscope is set up whose spectrum is formed at the slit of the first. Here the bolometer is placed and its indications read for several points in the spectrum. The bolometer is then replaced at its usual stand and energy curves of the small portions of spectrum it has just been measuring are taken. These bits of spectrum, it will be seen, have suffered absorption in the main spectroscope since the corresponding deflections were first taken in the first spectrum at the slit. Therefore the several quotients of the areas under the bits of energy curve to the deflections obtained prior to absorption are in proportion to the transmission of the spectroscope at the several wave lengths.

In the second part of the procedure two freshly silvered mirrors are placed parallel to each other in such a way that the beam of the siderostat mirror strikes the first, is reflected to the second, and thence to the spectroscope. This causes the spectrum to be weaker at all wave lengths by loss experienced from two reflections than when obtained with the beam from the siderostat mirror direct. Thus is the absorption of the two mirrors determined, and by replacing the siderostat mirror temporarily by one of them, its absorption follows at once. These determinations of the absorption of the apparatus have been made several times, but I will not here give their results more in detail, which are in general accordance with those already reached by you.

Absorption of the atmosphere and selective absorption of water vapor.—Since January 20 all favorable opportunities have been used to take quick speed energy curves. These have been made with quite different altitudes of the sun. Sometimes as many as 15 have been taken in one day, and 160 were secured between January 20 and July 1. These curves are studied from two points of view, first, as regards the variation in height for single wave lengths with different altitudes of the sun; second, as regards the variation in area and especially the areas of the great regions of water-vapor absorption. The first kind of examination leads to the determination of the general absorption of the air, the second to fixing the variations in amount of the solar radiation and of the special selective absorption of water vapor.

To illustrate the first method of study, let us suppose several energy curves to have been taken in a single clear day, during which the barometer height was (B), and let (B_0) be the standard barometric height, generally taken as 76 cm. From the altitudes of the sun as computed from the hour angles and declination, the air mass (m) is determined. This quantity represents the ratio which the mass of air traversed by the solar beam bears to that mass of air which would be traversed if the sun was directly overhead. If we suppose (e) to represent the amount of radiant energy per square centimeter of a certain wave length which reaches the earth's surface, and (e_0) the amount prior to absorption by the earth's atmosphere, and let (a) be the proportion transmitted per unit air mass, then by the well-known formula of Bouguer:[a]

$$e = e_0 a^{m\frac{B}{B_0}}$$

But since the height (d) of the bolographic energy curve at the wave length in question is proportional to (e), we may write:

$$d = ke = ke_0 a^{m\frac{B}{B_0}}$$

[a] As you have pointed out, this formula is grossly abused frequently in that (a) is treated as if constant for all wavelengths. Thus entirely erroneous results are reached. The present use of the formula merely assumes (a) constant over the extremely narrow region of spectrum covering the bolometer strip at any given instant. As thus applied it is believed that good results are reached. If single wavelengths were in question it is believed the formula would be exact.

where (k) is an instrumental factor connected with the width of the slit, the absorption of the optical surfaces, the quality of the bolometer, and the sensitiveness of the galvanometer. We may assume (c_o) and (k) to be constant for the short space of time occupied by one day's observations. We then obtain the following equation:

$$\log.\ (d) = m^{\frac{B}{B_o}} \log.\ (a) + \log.\ (kc_o)$$

of which the last term is constant. This equation is in the form of the equation of a straight line, so that if we make a plot in which heights are proportional to logarithms of (d), and horizontal distances to values of $(m^{\frac{B}{B_o}})$, the various observations should determine a straight line the tangent of whose inclination is the quantity log. (a).

The procedure has been followed with many of the energy curves already taken, and from results of four of the clearest days I select the following data for a few wave lengths, graphically represented in Fig. 3. The coefficients of transmission are the percentages of the solar radiation of the given wave lengths which are transmitted by a vertical column of air at standard barometric pressure. It is not the selective transmission in bands, but the general transmission at the given wave lengths which is here in question.

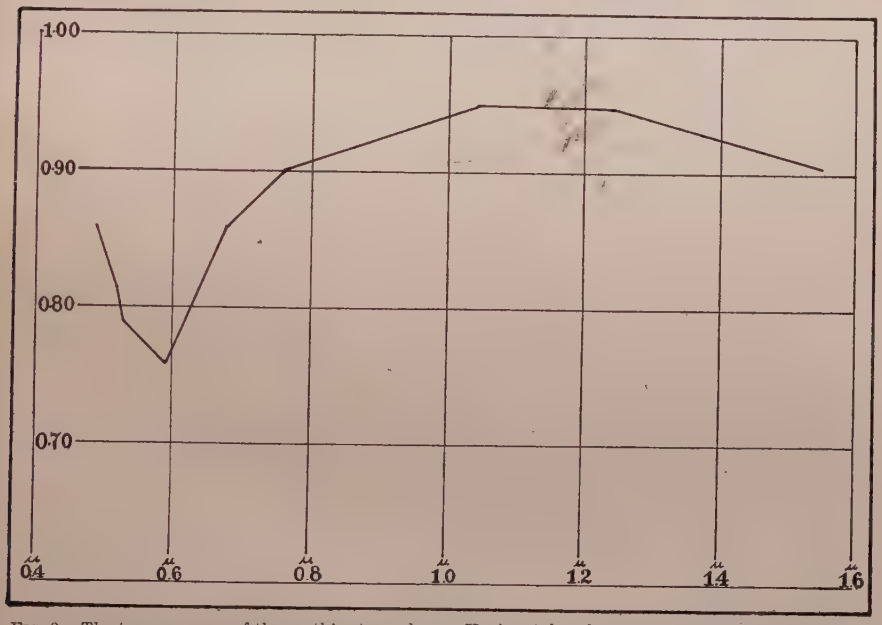


FIG. 3.—The transparency of the earth's atmosphere. Horizontal scale represents wave lengths. Vertical scale exhibits proportion of incident light transmitted by vertical column of air at standard barometric pressure.

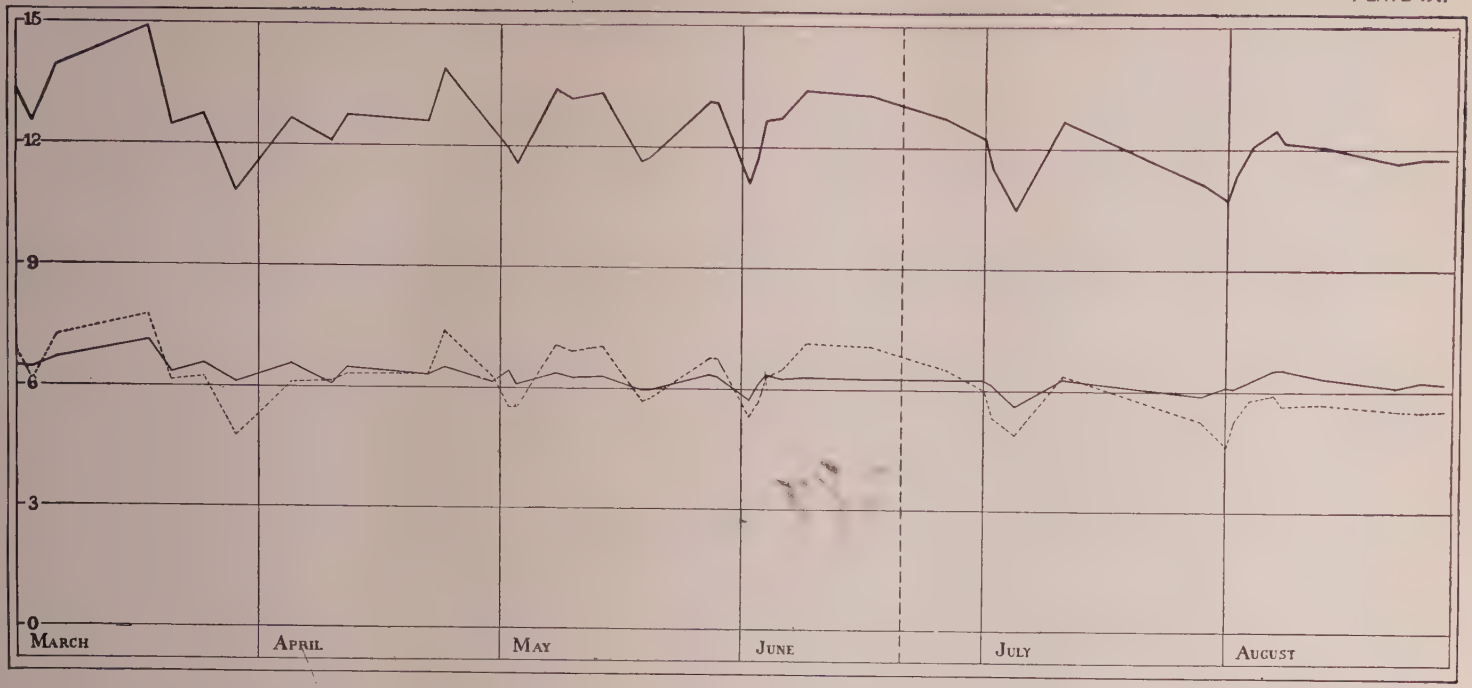
Provisional values of coefficients of atmospheric transmission.

Wave length.		0.486 μ.	0.518 μ.	0.527 μ.	0.589 μ.	0.760 μ.	1.05 μ.	1.30 μ.	1.75 μ.
Date.	Range of air mass.	Coefficients of transmission.							
Oct. 25, 1901	1.67 to 3.05		0.811	0.792	0.818	0.916	0.948	0.962	0.942
Nov. 2, 1901	1.70 to 3.50		0.800	0.794	0.665	0.900	0.942	0.966	0.940
Mar. 21, 1902	1.30 to 2.50	0.830	0.832	0.780	0.798	0.857			0.849
May 8, 1902	1.07 to 1.45	0.890			0.757	0.929	0.955	0.914	0.889
Mean		0.860	0.814	0.789	0.759	0.900	0.948	0.947	0.905

It will be noted that though the agreement of these values would not be held very close in some lines of physical investigation, yet when it is taken into account that an invisibly thin cloud or an unaccountable disturbance of the galvanometer is sometimes sufficient to make an energy curve erroneous, the results promise well. It is yet too early to do more than call attention to the depression in the curve in the yellow and green at about 0.55 μ. This may be due to the absorption of water vapor, but experiments here given are preliminary. Results of interest appear probable in relation to the applicability of Bouguer's formula to wave lengths where selective absorption is active, and relating to the variation of atmospheric absorption through the day and through the year. It will be observed from the preceding table that the general absorption is least at wave lengths 1.05 μ and 1.30 μ in the infra red, where the transmission coefficient rises to 95 per cent.

As an illustration of the results obtained from measures of areas, and representing total radiation for considerable ranges of wave lengths, I call attention to the diagrams of Plate IX. In these diagrams the horizontal distances represent the time of the year, the vertical distances the corrected areas or total radiation received, corresponding to certain selected portions of the curve. The observations on which these selected areas are based were all made at or near noon. In order that the several spectrum energy curves might be comparable as regards instrumental conditions, all the directly measured areas were multiplied by a factor chosen so that, as corrected, the curves would all be of a uniform height of 10 centimeters at 1.05 μ, where the transmission, as I have just pointed out, is greatest. The upper line in Plate IX represents the total area included under the energy curve between wave lengths 0.76 μ and 1.98 μ. The lower full line includes the summation of several portions of this area known to be least subject to diminution by the absorption of water vapor, namely, the regions 0.97 μ to 1.10 μ, 1.16 μ to 1.33 μ, 1.49 μ to 1.82 μ. Crossing it at many points is a dotted line representing the summation of the remaining areas, including the great water vapor bands of the infra red to a wave length of 1.98 μ. These curves (prolonged through July and August for additional interest) show how important are the effects of water vapor on the direct radiations we receive from the sun. In order to compare the several parts of the curves justly, times equidistant from the June solstice should be selected so that equal air masses are traversed. The differences in air mass are not sufficient to produce much effect upon the general absorption in this region, but affect the water-vapor absorption appreciably. It will be seen that the total solar radiation in the region between 0.76 μ and 1.98 μ was on an average fully 15 per cent greater in March of this present year than in August, on account of the greater absorption of water vapor. Comparing the separate points, it may be seen that the variation in water-vapor absorption, while, as we have just seen, on the whole seasonal, is yet very fluctuating from day to day. Thus, for example, it could be inferred from a discussion of the curve in March that in two apparently equally clear days of the same week there was a difference of 15 per cent in the solar radiation received, owing to the difference in water-vapor absorption. In sharp contrast to the variability of the areas of the water-vapor absorption regions is the behavior of the remaining portion of the spectrum. This contains some secondary but still considerable water-vapor bands, so that some fluctuation still remains. But it seems possible as a result of this study that certain large regions, notably that between wave lengths 0.97 μ and 1.10 μ, are so nearly unaffected in area by any terrestrial atmospheric absorption that they can serve to indicate if the total solar radiation fluctuates from year to year.

Absorption of the solar envelope.—The experiments on the absorption of the solar envelope briefly mentioned in last year's report were continued as far as practicable with the apparatus available. Fig. 4 shows the results thus far reached. Horizontal distances are proportional to wave lengths, vertical distances to transmission coefficients. These transmission coefficients are not exactly similar to the ones just given for the earth's atmosphere. If we represent the intensity of the radiation we



VARIATION OF THE AMOUNT OF SOLAR RADIATION IN THE INFRA-RED SPECTRUM INCLUDED BETWEEN WAVE LENGTHS 0.76μ AND 2.0μ.

From bolographic studies of 1902. Upper curve represents total radiation in this region; dotted curve represents portion notably affected by absorption of water vapor in the earth's atmosphere; lower full curve represents portion comparatively unaffected by water vapor absorption.

receive from the center of the solar disk as unity, then as we measure farther and farther from the center the intensity will diminish, owing to the absorption the rays experience in the ever-increasing length of path they traverse in the solar envelope. Different wave lengths are differently diminished. The figure gives the fractions remaining for the intensity at points distant 95 per cent and 98 per cent of the radius from the center. Referring to Fig. 3, we see that in both the solar and the terrestrial atmosphere the absorption is least in the infra red, and indeed follows a somewhat similar curve throughout the range of wave lengths here investigated. The accuracy of the results is not great enough to insist on the significance of the inflections which appear in the curves given, but here also there is a similarity between the terrestrial and solar curves. Owing to the imperfection of the large solar image, due to "boiling" of the air, to the rotation of the field by the siderostat, and to the fact that the image was enlarged by a convex mirror from about 3 centimeters diameter to 40 centimeters, it seemed useless to attempt projected further measurements, including some on the radiation of sun spots, until some better way of producing the solar image was arranged for. Experiments which have been made for this purpose will be described under another caption.

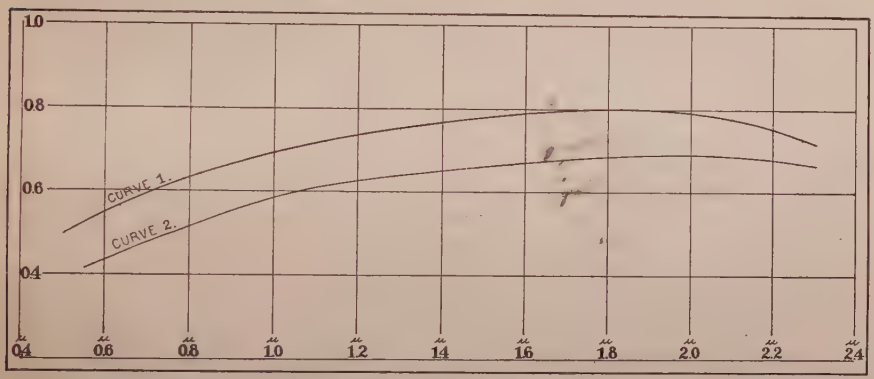


Fig. 4.—The transparency of the solar envelope. Horizontal scale represents wave lengths. Vertical scale exhibits relative amount of radiation from the edge and center of the sun. Curve 1 is for points 95 per cent of radius distant from sun's center. Curve 2 is for points 98 per cent of radius distant from sun's center.

I take much pleasure in saying that the work of taking energy curves for determining solar and terrestrial absorption, the measurements of ordinates and areas, and preliminary reductions, only a very few of which I have here given, have been efficiently done by the junior assistant, Mr. F. E. Fowle.

Sensitive galvanometer.—In my last report I stated at some length the progress made and looked for in increasing the working sensitiveness of the galvanometer. It was stated that a modified form of needle system was proposed, much heavier and probably not less sensitive than those then in use. The design there referred to was based partly on experiments which had been made which showed that two small thin magnets could be placed within a distance equal to their own diameter without suffering much loss of combined magnetic moment. If this proved applicable to a system of numerous magnets it would be possible to increase the number of magnets to a hundred or more without loss of sensibility overbalancing the gain which would result from decreasing the relative moment of inertia of the nonmagnetic material. Shortly after my return from Sumatra a needle system of this kind was constructed, containing 120 magnets, 60 at each end, separated by spaces equal to the thickness of the needles. The problem of arranging them thus proved a pretty difficult one, but was solved, though after a fashion not quite satisfactory. It was a disappointment to find, however, that the sensitiveness of this system was only

one-third as great as that of the very light system then in use. To discover the cause of this a large number of experiments were made on the magnetic moment of needles of various sizes and shapes between weights of 0.0006 and 0.0030 milligrams, and on combinations of them at various distances. In the course of this investigation it was again shown (as had already been accepted here) that for magnets between the limits of five and fifty times as long as thick, the magnetic moment is directly proportional to the product of the weight by the ratio of the length to the diameter. This relation is, and has been for some years, a fundamental consideration in the construction of galvanometer needles here. But though no error appeared in this assumption, it was found that the other, that a great number of magnets could be combined without much loss within a distance apart equal to their diameter, was quite unsound. While this is the case for two magnets, it is not so for a larger number. They can not advantageously be placed at a distance apart less than 3 diameters without a considerable loss of total magnetic moment. This is the case whether the needles are first magnetized and then approached or magnetized in position. It is slightly better to keep them 4 diameters apart. This condition prevented making needle systems such as were proposed, but a greater weight of system seemed so very desirable that new devices were discussed. Six needles in a group seemed to be about the limiting number which could be used with advantage, so that to get more than 12 needles to a system required more than 2 groups to put them in. It was proposed to use 16 coils instead of 4 in the galvanometer, thus allowing 8 groups of needles or 48 in all. This involved a deliberate sacrifice of sensitiveness. Allowing for the several counterbalancing effects, it was computed that the sensitiveness at a time of swing of one second would be only about one-half or two-thirds as great for a 16-coil instrument as for a 4-coil instrument of equal resistance. But it was confidently believed that the steadiness of the former and its better capacity for use at higher times of swing would more than compensate this loss.

Accordingly a 16-coil galvanometer, with needle system containing 48 magnets and weighing nearly 10 milligrams, was constructed. Its sensitiveness was found to be about as computed, and its steadiness is so much superior to that formerly employed, both as regards drift and tremor, that it has been used since December with most marked advantage for bolographic work. So entirely satisfactory has it proved that another 16-coil galvanometer with needle system, weighing 0.012 grams, has been constructed for use on the great suspension system of which I spoke last year. A large number of separate needles are weighed, measured, and their magnetic moments determined before the 48 are selected, so that no opportunity is allowed for a few weak ones to lower the sensitiveness and injure the astaticism of the combination. The system is strongly magnetized after its completion by the aid of a 16-coil electro-magnet. In the making up of these needles to form the system, a new process of fastening the magnets has been devised by which results very superior to any heretofore obtained here are reached.

Further experiments on the exhaustion of the air from the galvanometer case have been made. It was found extremely difficult to prevent leakage of air into the instrument, and this when it occurred caused "drift." This difficulty has at length been practically overcome. It had been supposed that a pressure of 1 millimeter or thereabouts would be quite as low as would be necessary with a 10-second single swing. But even with the heavy needle system now in use, the damping became excessive at 2.5 seconds single swing and 0.08 millimeter pressure. The pressure was reduced to 0.20 millimeter, and next the time of single swing was raised to 5.5 seconds, before damping became excessive. The very promising result was reached that *the deflection was proportional to the square of the time of swing* up to a time of single swing of above 5 seconds. Further exhaustion of the air proved impossible at the time, owing to the vapor pressure of the wax and grease used about the galvanometer. But by a modification of the outer case, it is believed that this difficulty can be overcome, and that

the aim last year set forth to carry the proportionality between deflection and square of the time of swing up to 10 seconds single swing will at length be reached. Great steadiness was observed at 5.5 seconds swing. A deflection of 1 millimeter on the scale then actually corresponded to a current of only $\frac{5}{1000000000000}$ amperes in the galvanometer. The resistance of the instrument is only 1.6 ohms. A current of one-tenth this magnitude—or 5×10^{-12} amperes—could actually have been measured. Further advance is confidently expected.

Personal-equation machine.—You have placed at the Observatory for trial an instrument of your own design intended to eliminate the so-called personal equation of individual observers in transit observations. The principle of this instrument consists in substituting a judgment of the place where a sudden phenomenon occurred for the time when it occurred. To use an illustration which you have already employed, in case the dark field in which only the star is seen moving were illuminated every two seconds by a self-recording flash which showed the central wire, and if by pure accident the star was caught in an exact bisection when the flash came—an accident against which the chances are perhaps more than a hundred to one—it is evident that in this rare and improbable event there would be no personal equation to allow for, if the time of flash within two seconds were noted by the observer. Now, the object of the following mechanism may be said to be to make this accident happen every time.

This being understood, as first tried with the apparatus which you furnished, the design was to illuminate the cross wires of the transit instrument by automatically recorded electric flashes occurring at regular intervals equal to the time elapsing between passages of the star across successive wires. An adjustable mechanism allowed the observer to hasten or defer the whole system of flashes until by successive adjustments he caught the exact instant when the star was bisected by the dark wire in the instantaneously bright field. Several such adjustments could be made during a single star transit across the numerous wires of the tally, and immediately after each satisfactory bisection a signal was made on the chronograph by a key in the hand of the observer, so that only such recorded flashes as were thus distinguished were used in determining the time of transit.

In order to test the value of this instrument an artificial star was caused to move through the field at a rate about equal to that of a real equatorial star. This star was moved by a screw and clockwork of great accuracy, and always through the same portion of the screw. It was also provided that when the star was exactly bisected by the middle wire an electrical contact was broken, so that the star recorded its own transit upon the chronograph. The adjustment of the contact for this bisection was made at leisure with the star stationary, and was therefore not subject to the personal error of transit observations. Accordingly, after determining all the wire intervals, it was entirely easy to measure the personal equation of the observer, whether he used the personal-equation machine or the ordinary method, merely by comparing his observed time of transit with that recorded by the star itself. Upon trial it was found that the personal equation of the several observers was not wholly prevented by employing the machine in the manner described; that is, by bisections judged during instantaneous flashes. The writer, for example, observed about 0.12 second too early by both methods.

It seemed probable that the observer was still biased in his judgment by watching the march of the star through the field across the very faintly showing wires, which are always to be made out by the stray light of the star and sky, even though there is no illumination by the flash. Accordingly it seemed to promise success to alter the arrangement so that the star would be hidden except at the instants corresponding to those when the flash had formerly appeared, and to steadily illuminate the field as is usual in transit instruments. In the test this was easier than in actual

practice, for the artificial star itself could be obscured by a shutter immediately in front of it, which could be removed instantaneously by the electric signal from the personal-equation machine. The same thing could, however, be done at the focal plane of the telescope in real use.

Upon trial this device justified all hopes. Three observers whose habit is to observe, one too early, one too late and the other very close to the true time, were found all to observe as close to the truth as the accidental errors would admit, which in the case of the 3-foot focus transit instrument employed was generally within 0.03 second. In other words, personal equation seems to be wholly eliminated by this procedure. The general design may be applied without great expense to any outfit of transit and chronograph.

Provision for great solar image.— As already said, the experiments on solar absorption, nature of sun spots and other phenomena required for their successful continuation a large solar image free from rotation and as free as possible from "boiling" and from optical defects. Among these latter it will be evident that variations in absorption and in magnification at different portions of the image were quite serious, as well as the ordinary defects of definition. To magnify a small image to the required diameter seemed to be very undesirable, for several reasons, chief of which were the optical defects just spoken of and the increased "boiling" due to the heating at the small focal image. The use of the siderostat was objectionable on account of its rotating the field.

You have therefore decided to use the coelostat and a concave mirror of long enough focus to form the image of the desired size without a second magnification. The coelostat, which I understand you to have been first employed by you as a working instrument on a large scale (in 1882), is essentially a plane mirror rotating on an axis parallel with the axis of the earth at the rate of one revolution in forty-eight hours. It is unable to send the reflected beams from objects at different declinations in the same direction, and if used to provide a horizontal reflected beam from the sun, must send it in a more southerly direction in summer than in winter. In this latitude the extreme directions reached by a horizontal coelostat beam would be, respectively, about 30° north and 30° south of an east and west line. To avoid moving the concave mirror and other apparatus to suit the shifting direction of the coelostat beam, it has been determined to place a second movable plane mirror close to the coelostat to reflect the beam to the concave mirror, retaining the latter fixed. This mirror is so mounted that it can be wheeled north or south along a track situated as close to the coelostat as possible. This track is designed to curve round the south end of the coelostat so that the second mirror can be either east or west of the coelostat as desired, and it is intended to use it east in the morning and west in the afternoon. A concave mirror of 18 inches aperture and 140 feet focus which you have ordered will be placed about 60 feet north of the coelostat. Its beam on the way to its focus will pass directly under the coelostat mirror and between the morning and afternoon positions of the second plane mirror. The coelostat mirror is thus about 2 feet higher than the concave mirror and about 1 foot higher than the second mirror, so that the latter casts no shadow on the coelostat mirror except for very low sun at the times of the equinoxes. On account of the unfavorable inclination of the coelostat mirrors at certain times of the year and day, it is determined also to provide for the use of the two plane mirrors as a polar siderostat, since only slight changes are required to alter a polar siderostat into a coelostat, and the reverse. If used as a polar siderostat, the gain in effective mirror surface will be offset by having a rotating image.

In either case, as thus arranged, it is possible to completely inclose the beam of light in suitable tubes after it reaches the coelostat, and even before, by a tube moved to follow the sun. The only use of such tubes is to prevent the "boiling" or apparent motion around the edges of the image due to air waves in the path of the beam,

and several quite decisive experiments were made by your direction to determine their effectiveness.

Experiments on "boiling" of the image.—I add a few words, partly in anticipation, in reference to your newly-introduced device for preventing the well-known effect of "boiling" the telescopic image, a difficulty due to the earth's atmosphere and which has existed always and everywhere, and which has seemed until lately so insurmountable that it has not even been thought of as subject to correction. The device that you have suggested consists essentially not in keeping the air still within and without the telescope tube, but in violently agitating it over as great a range as possible. For this purpose, under your instructions and with the object of rehearsing on a small scale what, if the device is successful, will be later tried on a large one, a silvered glass mirror of 5 inches diameter and 40 feet focus has been set up in a tube with several concentric walls, so as to leave the interior air as still as possible. In preliminary experiments the air, in spite of these precautions in the installation, gave such "boiling" of the image as to seriously prejudice the definition, and this, although the 40-foot tube had no less than three walls, being 7 inches in interior diameter and 15 inches in exterior diameter, and inclosing the beam all the way from a second plane mirror near the coelostat to the concave mirror and thence to the focus. Though this tube containing the stillest air of the most uniform temperature was sheltered throughout by a canvas tent, the "boiling" was but a little diminished. Nothing was gained by diminishing the aperture of the several mirrors down to 1 inch in diameter, and all this was only what had been anticipated from the ordinary experience of astronomers. A 12-inch blower run by an electric motor was now caused to exhaust air from the inner tube at a half dozen points along the tube, and to force air in at other points alternate with these, so as thus violently to disturb or "churn" the air by forcing a vigorous circulation of it along the whole path of the beam from the cœlostat to the solar image. This unquestionably reduced the "boiling." An artificial star was now provided at the focal plane, the plane mirror near the cœlostat was placed at right angles to the tube, and thus the concave mirror, acting as both collimator and objective, brought the star image to focus at the star itself. Here it was examined with an eyepiece. With still air the definition was often very poor. The image assumed very variable shapes, with wings or streamers; and being also colored by diffraction effects, reminded one of a kaleidoscope field. On starting the blower the definition immediately became sharp. Violently stirring the air in the tube, therefore, eliminates the "boiling" within the tube and (paradoxically) produces a still image. As before said, the solar image was clearly improved by the stirring; but further improvement was still to be desired. Accordingly a tin tube 44 feet long, with two walls of 11 inches interior diameter and 16 inches exterior diameter, was provided and arranged to point toward the sun, as shown in Plate VI, so that the beam passed down through it before reaching the mirror system. This tube was connected to the blower exactly like the horizontal one, and both could be stirred at once. There was very marked "boiling" before starting the blower. This nearly disappeared while the blower was running. One observer estimated the "boiling" as four-fifths overcome; another thought little more than a quarter remained, and all were unanimous that what was left was very little prejudicial to the definition. This last result is so surprising that I feel constrained to add that the experiments so far are not exhaustive, having been carried on but a short time, and without that solidity of piers which would allow of exact estimate or photographic determination of the "boiling" of the solar image before and during agitation of the air in the tube, as distinguished from mechanical jarring. Further experiments are in progress. That agitation is of very great advantage to diminish "boiling" there is no question, but the exact measure of the advantage for all circumstances of bad seeing requires further study. Incidentally, the air blast has the added advantage of keeping the mirrors at uniform temperature. This and the abolish-

ment of "boiling" in the tube are found to prevent those vexatious changes of focus so common in solar work.

These experiments, which I am free to say seemed to me when first proposed by you of a kind to increase rather than diminish "boiling," have in fact proved thus far almost wholly successful in eliminating it. The experiment with an ordinary equatorial has not yet been tried, but for a horizontal telescope, such as is here proposed, the scheme is demonstrable and feasible.

Radiation of the Cuban firefly.—In continuance of your observations on the cheapest form of light, two specimens of *Pyrophorus noctilucus* were loaned to the Observatory by kindness of Professor Howard, of the Agricultural Department. The radiation of the thoracic-light regions of these insects was briefly studied by the aid of the bolometer and photometer. The insect was placed in the center of curvature of a concave mirror of 50 centimeters aperture and 1 meter focus. In the conjugate focus was the most sensitive bolometric arrangement in the possession of the Observatory, connected to the galvanometer used for bolographic work. A glass plate was placed before the bolometer to cut off body radiation. Nothing whatever could be observed to indicate any heating effect from the light of the insect. A portion of the flame of a standard sperm candle equal in area to the light spot of the insect gave such a deflection that had the radiation from the insect been $\frac{1}{800}$ as great in amount it could not have escaped observation. On comparing the light from the candle and that from the insect by the aid of a photometer it was found that area for area the insect's light-giving capacity was one-eighth as great as that of the candle. Its actual candlepower was $\frac{1}{1600}$. Not counting the very considerable candle radiation not transmissible by glass, it therefore appeared that the firefly gave his light at less than $\frac{1}{10000}$ the expenditure of energy required for an equal light from the standard sperm candle. You will be gratified that while these observations evidently confirm your earlier experiments they show the great advance since then in the sensitiveness of the bolometer.

PERSONNEL.

The observing staff has been unchanged with the following exceptions: Dr. C. E. Mendenhall was employed as temporary assistant up to August 3, 1901, and Dr. N. E. Gilbert as temporary assistant, beginning June 16, 1902.

SUMMARY.

During the past year satisfactory progress has been made in the improvement of the galvanometer. Successful experiments have been made under the system first proposed by you by which personal equation in transit observations is avoided, and still others, which seem to be of great practical importance, by which the "boiling" of the telescopic image either of sun or star shows promise of being largely overcome. A comparison of the light and heat of the standard sperm candle with that of the firefly showed the latter to be more than 10,000 times more economical as a source of light.

The great purpose of the observatory—the investigation of the sun and of its influence on the earth—has been at all times continued.

Respectfully submitted.

C. G. Abbot,
Aid Acting in Charge, Astrophysical Observatory.

Mr. S. P. Langley,
Secretary of the Smithsonian Institution.

Appendix VI.

REPORT OF THE LIBRARIAN.

Sir: I have the honor to present herewith the report of the operations of the library of the Smithsonian Institution for the fiscal year ending June 30, 1902.

The number of volumes, parts of volumes, pamphlets, and charts recorded in the accession books of the Smithsonian deposit, Library of Congress, during the fiscal year is shown in the following table:

	Quarto or larger.	Octavo or smaller.	Total.
Volumes	465	1,213	1,678
Parts of volumes	13,802	7,032	20,834
Pamphlets	591	3,141	3,732
Charts			414
Total			26,658

The accession numbers run from 438,893 to 445,523.

The greater part of these publications have been sent to the Library of Congress, amounting during the past year to something over 188 boxes, 25 bags and packages, which are estimated to have contained the equivalent of 8,520 octavo volumes, this being a sending independent of that of the International Exchanges.

The decrease in the number of entries in the accession book and the periodical record as compared with last year will be accounted for by the large number of strictly Government documents which the Smithsonian Institution now sends direct to the Library of Congress through the Bureau of International Exchanges. This arrangement has been carried on in accordance with the understanding had between the Secretary and the Librarian of Congress.

The additions to the libraries of the Secretary, the Office, and the Astrophysical Observatory number 496 volumes, pamphlets, and charts and 2,587 parts of volumes, making a total of 3,083 and a grand total of 29,741. On the card catalogue of serial publications about 22,234 entries were made.

The universities at the following places have sent inaugural dissertations and academic publications:

Baltimore (Johns Hopkins).	Halle a Saal.	Lund.
Basel.	Heidelberg.	Marburg.
Berlin.	Helsingfors.	Missoula, Mont.
Bern.	Jena.	Philadelphia.
Bonn.	Kazan.	St. Petersburg.
Breslau.	Kiel.	Strasburg.
Erlangen.	Konigsberg.	Toulouse.
Frieburg, iB.	Leipzig.	Wurzburg.
Giessen.	Liege.	Yuriev.
Griefswald.	Louvain.	Zurich.

The policy of increasing the library by exchange has been continued with favorable results. In carrying this out, 877 letters were written for new exchanges and for completing series already in the library; 317 periodicals were added to the list; 451 defective series were either completed or partly filled, according to the publisher's ability to supply the numbers requested. About 1,800 letters were received and filed in jackets on which a synopsis of each letter is given.

The card catalogue of correspondence for reference has been continued, as well as the issuing of orders for Smithsonian publications sent in exchange. When single numbers are reported as missing, postal cards are forwarded requesting that they be supplied. Corresponding postal cards are sent as acknowledgments of receipts. About 1,090 numbers were asked for, and 703 supplied.

The reference room and the reading room, the proceedings and transactions of learned societies being in the former and the scientific periodicals in the latter, have been used not only by the staff of the Smithsonian Institution, but by many other departments of the Government. In the reading room alone 3,208 periodicals and 25 bound volumes were withdrawn for consultation.

The sectional library at the National Zoological Park has been added to, and the collection is growing in importance.

In the Institution there are maintained, besides the Secretary's library, the office library, the employees' library, three sectional libraries—Aerodromics, International Exchanges, and Law Reference.

In the Astrophysical Observatory attention has been given to the sets of periodicals. These were gone over, missing parts ordered, and 46 volumes bound.

The employees' library has increased in popularity, and during August last a branch extension was made to the Zoological Park. The books are placed in an upright box made for the purpose, with a capacity of 40 volumes, and sent out once a month. The library now contains 1,370 volumes, and during the year 2,379 books were borrowed.

The librarian having, with the permission of the Secretary, relinquished his position as custodian of the Smithsonian deposit at the Library of Congress, to render possible his attention to certain duties outside of the Institution, Mr. Paul Brockett was on April 1, 1902, appointed assistant librarian of the Smithsonian Institution and custodian of the Smithsonian deposit.

Mr. Brockett will attend to matters relating to the Smithsonian Institution library and the Institution's interests at the Library of Congress. During the few months he has been in the library he has made himself familiar with the various details of the office and the Smithsonian deposit.

Early in November, 1901, Gen. John Watts de Peyster presented to the Institution his magnificent collection of books and pamphlets relating to Napoleon Bonaparte, to be known as the "Watts de Peyster Collection, Napoleon Bonaparte." It is a very complete one, containing books from all countries and in all languages. In it I have noticed many rare volumes, and the valuation of $10,000, put upon it by General de Peyster, I think very low, for a number of the books were long ago out of print and have now reached the point where no price can be put upon them. There have been received from General de Peyster nearly 2,000 volumes, which are now in temporary cases, but the number of books has outgrown the space provided. A running list has been made and sent to General de Peyster for his information, and at a very early date suggestions for the permanent care and the making of a card catalogue of this collection will be presented for your consideration.

The art room has received considerable attention, and, in accordance with the Secretary's wish, the collection of photographs of representative portraits by the old masters has been returned from the Buffalo Exposition and hung upon the walls in chronological order. The question of extending the Parthenon frieze around the entire room has been taken up and it is hoped that it will be in place during the summer.

With the allotment from the Smithsonian Institution funds for the maintenance of the International Catalogue of Scientific Literature, a regional bureau has been established and the work carried on. The temporary provision for the coming year will warrant only the employment of the same force, which is entirely inadequate to properly care for the numerous duties imposed. A sum of at least $10,000 per annum is needed for the United States Regional Bureau, and it is hoped that Congress will, now that the publication is actually begun, appropriate the necessary funds for the representation of the United States in an undertaking which will render aid to all branches of scientific learning throughout the country.

The work done for the year ending June 30, 1902, is in brief as follows: (1) The general organization of a regional bureau, including means of collecting and disposing of all scientific matter published in the United States; (2) making a list of the periodicals of the United States coming within the scope of the catalogue; (3) preparing and classifying index reference slips to the scientific publications of 1901 and forwarding these slips to the London Central Bureau. The slips forwarded up to June 30, 1901, number 6,990. The first two volumes of the International Catalogue of Scientific Literature for 1901 have appeared. They are: Botany, Part I, of 1901, and Chemistry, Part I, of 1901, and were published in May and June of the present year.

The crowded condition of the National Museum Library has been relieved by the addition of galleries in two of the halls of the Museum building. These contain a total floor space of 2,592 square feet. During the coming year the entire series of scientific publications will be rearranged, thus increasing the usefulness of the library.

The files of periodicals have been gone over and the missing numbers obtained. Owing to the small force, this has been done at odd times when the regular work would allow, and has resulted in the completing of 31 of the 106 sets examined.

The accessions number a total of 19,553 books, pamphlets, and periodicals, of which 3,660 were a portion of the Smithsonian deposit; 23,149 books were borrowed. The number of periodicals entered was 9,297, and 2,189 cards were added to the Authors' Catalogue of the Museum Library. This last does not include, however, 1,605 cards for books and pamphlets recatalogued.

The sectional libraries established in the Museum are as follows:

Administration.	Fishes.	Oriental archæology.
Administrative assistant.	Geology.	Paleobotany.
Anthropology.	History.	Parasites.
Biology.	Insects.	Photography.
Birds.	Mammals.	Prehistoric anthropology.
Botany.	Marine invertebrates.	Reptiles.
Children's room.	Materia medica.	Stratigraphic paleontology.
Comparative anatomy.	Mesozoic fossils.	Superintendent.
Editor.	Mineralogy.	Taxidermy.
Ethnology.	Mollusks.	Technology.

Respectfully submitted.

CYRUS ADLER, *Librarian.*

Mr. S. P. LANGLEY,
Secretary of the Smithsonian Institution.

Appendix VII.

REPORT OF THE EDITOR.

Sir: I have the honor to submit the following report on the publications of the Smithsonian Institution and its bureaus during the year ending June 30, 1902.

I. SMITHSONIAN CONTRIBUTIONS TO KNOWLEDGE.

1309. Hodgkins fund. Experiments with Ionized Air, by Carl Barus, Hazard professor of physics in Brown University. City of Washington: Published by the Smithsonian Institution, 1901. Quarto. Pages x+95.

801. Experiments in Aerodynamics, by S. P. Langley. Second edition. (First edition published in 1891.) City of Washington: Published by the Smithsonian Institution, 1902. Quarto. Pages II+115, with Plates I–XII.

II. MISCELLANEOUS COLLECTIONS.

1259. List of Observatories. City of Washington: Published by the Smithsonian Institution, 1902. Octavo. Pages 48.

1312. Index to the Literature of the Spectroscope (1887–1900, both inclusive) [continuation of the previous index by the same author published in 1888], by Alfred Tuckerman. Washington City: Published by the Smithsonian Institution, 1902. Octavo. Pages III+373. This index is brought to the end of the year 1900, after which date the International Committee for Indexing Scientific Literature begins the continuation of the work of cataloguing spectroscopy.

1313. A Bibliography of the Analytical Chemistry of Manganese, 1785–1900, by Henry P. Talbot and John W. Brown. City of Washington: Published by the Smithsonian Institution, 1902. Octavo. Pages VIII+124.

1174. Smithsonian Miscellaneous Collections. Vol. XLI. City of Washington: Published by the Smithsonian Institution, 1902. Octavo. Pages V+1186.

CONTENTS.

Index to the Literature of Thallium, 1861–1896, by Martha Doan. Washington, 1899. (Number 1171.)

Index to the Literature of Zirconium, by A. C. Langmuir and Charles Baskerville. Washington, 1899. (Number 1173.)

A Select Bibliography of Chemistry, 1492–1897, by Henry Carrington Bolton. Section viii. Academic Dissertations. Washington, 1901. (Number 1253.)

On the Cheapest Form of Light, by S. P. Langley and F. W. Very. Washington, 1901. (Number 1258.)

List of Observatories, Washington, 1902. (Number 1259.)

Index to the Literature of the Spectroscope, 1887–1900, by Alfred Tuckerman. Washington, 1902. (Number 1312.)

A Bibliography of the Analytical Chemistry of Manganese, 1785–1900, by Henry P. Talbot and John W. Brown. Washington, 1902. (Number 1313.)

Chemical Societies of the Nineteenth Century, by Henry Carrington Bolton. Washington, 1902. (Number 1314.)

III. SMITHSONIAN ANNUAL REPORTS.

The annual report is in two parts or volumes, one devoted to the Institution proper and the other to the National Museum. The Smithsonian volume for 1900 was mentioned in the last report of the editor; the volume for 1901 was in type, though

the presswork, with the exception of the Secretary's Report, was not completed at the close of the fiscal year. The contents of the 1901 report are as follows:

1315. Journal of Proceedings of the Board of Regents of the Smithsonian Institution, report of executive committee, acts and resolutions of Congress. From the Smithsonian Report for 1901, pages XIII–LXVII. Washington: Government Printing Office, 1902. Octavo.

1311. Report of S. P. Langley, Secretary of the Smithsonian Institution, for the year ending June 30, 1901. Washington: Government Printing Office, 1901. Octavo. Pages v+140, with 13 plates.

1316. The Smithsonian Institution. From the Smithsonian Report for 1901, pages 145–151, with Plates I–VI. Washington: Government Printing Office, 1902. Octavo.

1317. Some Recent Astronomical Events, by C. G. Abbot. From the Smithsonian Report for 1901, pages 153–169, with Plates I–VI. Washington: Government Printing Office, 1902. Octavo.

1318. A Model of Nature, by Arthur W. Rücker. From the Smithsonian Report for 1901, pages 171–191. Washington: Government Printing Office, 1902. Octavo.

1319. A Century of the Study of Meteorites, by Dr. Oliver C. Farrington. From the Smithsonian Report for 1901, pages 193–197. Washington: Government Printing Office, 1902. Octavo.

1320. Recent Studies in Gravitation, by Prof. John H. Poynting. From the Smithsonian Report for 1901, pages 199–214. Washington: Government Printing Office, 1902. Octavo.

1321. On Ether and Gravitational Matter through Infinite Space, by Lord Kelvin. From the Smithsonian Report for 1901, pages 215–230. Washington: Government Printing Office, 1902. Octavo.

1322. On Bodies Smaller than Atoms, by Prof. J. J. Thomson. From the Smithsonian Report for 1901, pages 231–243. Washington: Government Printing Office, 1902. Octavo.

1323. The Exploration of the Atmosphere at Sea by Means of Kites, by A. Lawrence Rotch. From the Smithsonian Report for 1901, pages 245–249, with Plates I, II. Washington: Government Printing Office, 1902. Octavo.

1324. Solid Hydrogen, by James Dewar. From the Smithsonian Report for 1901, pages 251–261. Washington: Government Printing Office, 1902. Octavo.

1325. Utilizing the Sun's Energy, by Robert H. Thurston. From the Smithsonian Report for 1901, pages 263–270, with Plate I. Washington: Government Printing Office, 1902. Octavo.

1326. The New Radiations: Cathode Rays and Röntgen Rays, by A. Dastre. From the Smithsonian Report for 1901, pages 271–286. Washington: Government Printing Office, 1902. Octavo.

1327. Wireless Telegraphy, by Signor G. Marconi. From the Smithsonian Report for 1901, pages 287–298, with Plate I. Washington: Government Printing Office, 1902. Octavo.

1328. Transatlantic Telephoning, by William A. Anthony. From the Smithsonian Report for 1901, pages 299–306, with Plates I, II. Washington: Government Printing Office, 1902. Octavo.

1329. The Telephonograph, by William J. Hammer. From the Smithsonian Report for 1901, pages 307–312, with Plates I, II. Washington: Government Printing Office, 1902. Octavo.

1330. Color Photography, by Sir William J. Herschel. From the Smithsonian Report for 1901, pages 313–316, with colored plates I–III. Washington: Government Printing Office, 1902. Octavo.

1331. History of Chronophotography, by Dr. J. Marey From the Smithsonian Report for 1901, pages 317–340, with Plates I–IX. Washington. Government Printing Office, 1902. Octavo.

1332. The Aims of the National Physical Laboratory of Great Britain, by R. T. Glazebrook. From the Smithsonian Report for 1901, pages 341–357, with Plates I, II. Washington: Government Printing Office, 1902. Octavo.

1333. Emigrant Diamonds in America, by William Herbert Hobbs. From the Smithsonian Report for 1901, pages 359–366, with Plates I–III. Washington: Government Printing Office, 1902. Octavo.

1334. Bogoslof Volcanoes, by C. Hart Merriam. From the Smithsonian Report for 1901, pages 367–375, with Plates I–III. Washington: Government Printing Office, 1902. Octavo.

1335. The Antarctic Voyage of the Belgica during the Years 1897, 1898, and 1899, by Henryk Arctowski. From the Smithsonian Report for 1901, pages 377–388, with Plates I–VII. Washington: Government Printing Office, 1902. Octavo.

1336. The Sea in the Life of the Nations, by Alfred Kirchoff. From the Smithsonian Report for 1901, pages 389–399. Washington: Government Printing Office, 1902. Octavo.

1337. Forest Destruction, by Gifford Pinchot and C. Hart Merriam. From the Smithsonian Report for 1901, pages 401–405, with Plates I–IV. Washington: Government Printing Office, 1902. Octavo.

1338. Irrigation, by F. H. Newell. From the Smithsonian Report for 1901, pages 407–423, with Plates I–VII. Washington: Government Printing Office, 1902. Octavo.

1339. The Palace of Minos, by Arthur J. Evans. From the Smithsonian Report for 1901, pages 425–437, with Plates I–VIII. Washington: Government Printing Office, 1902. Octavo.

1340. The Engraved Pictures of the Grotto of La Mouthe, Dordogne, France, by M. Emile Rivière. From the Smithsonian Report for 1901, pages 439–449. Washington: Government Printing Office, 1902. Octavo.

1341. The Mind of Primitive Man, by Franz Boas. From the Smithsonian Report for 1901, pages 451–460. Washington: Government Printing Office, 1902. Octavo.

1342. Traps of the American Indians: A Study in Psychology and Invention, by Otis T. Mason. From the Smithsonian Report for 1901, pages 461–473, with Plate I. Washington: Government Printing Office, 1902. Octavo.

1343. The Abbott Collection from the Andaman Islands, By Lieut. W. E. Safford, U. S. Navy. From the Smithsonian Report for 1901, pages 475–492, with Plates I–VI. Washington: Government Printing Office, 1902. Octavo.

1344. The Development of Illumination, by Walter Hough. From the Smithsonian Report for 1901, pages 493–500, with Plates I, II. Washington: Government Printing Office, 1902. Octavo.

1345. Order of Development of the Primal Shaping Arts, by W. H. Holmes. From the Smithsonian Report for 1901, pages 501–513. Washington: Government Printing Office, 1902. Octavo.

1346. Boomerangs, by Gilbert T. Walker. From the Smithsonian Report for 1901, pages 515–521. Washington: Government Printing Office, 1902. Octavo.

1347. The Possible Improvement of the Human Breed under the Existing Conditions of Law and Sentiment, by Francis Galton. From the Smithsonian Report for 1901, pages 523–538. Washington: Government Printing Office, 1902. Octavo.

1348. The Fire Walk Ceremony in Tahiti, by S. P. Langley. From the Smithsonian Report for 1901, pages 539–544, with Plates I–III. Washington: Government Printing Office, 1902. Octavo.

1349. The Laws of Nature, by S. P. Langley. From the Smithsonian Report for 1901, pages 545–552. Washington: Government Printing Office, 1902. Octavo.

1350. The Children's Room in the Smithsonian Institution, by Albert Bigelow Paine. From the Smithsonian Report for 1901, pages 553–560, with Plates I–XX. Washington: Government Printing Office, 1902. Octavo.

1351. Salt and its Physiological Uses, by M. A. Dastre. From the Smithsonian Report for 1901, pages 561–574. Washington: Government Printing Office, 1902. Octavo.

1352. Santos-Dumont Circling the Eiffel Tower in an Air Ship, by Eugene P. Lyle, jr. From the Smithsonian Report for 1901, pages 575–592, with Plates I–X. Washington: Government Printing Office, 1902. Octavo.

1353. Automobile Races, by Henri Fournier and others. From the Smithsonian Report for 1901, pages 593–609, with Plates I–VI. Washington: Government Printing Office, 1902. Octavo.

1354. The Erection of the Gokteik Bridge, by Day Allen Willey. From the Smithsonian Report for 1901, pages 611–615. Washington: Government Printing Office, 1902. Octavo.

1355. The Great Alpine Tunnels, by Francis Fox. From the Smithsonian Report for 1901, pages 617–630, with Plates I–IV. Washington: Government Printing Office, 1902. Octavo.

1356. The Mutation Theory of Professor DeVries, by Charles A. White. From the Smithsonian Report for 1901, pages 631–640. Washington: Government Printing Office, 1902. Octavo.

1357. The Dinosaurs or Terrible Lizards, by F. A. Lucas. From the Smithsonian Report for 1901, pages 641–647, with Plates I–IV. Washington: Government Printing Office, 1902. Octavo.

1358. The Greatest Flying Creature, by S. P. Langley. Introducing a paper on the Pterodactyl Ornithostoma, by F. A. Lucas. From the Smithsonian Report for 1901, pages 649–659, with Plates I–VII. Washington: Government Printing Office, 1902. Octavo.

1359. The Okapi, by Sir Harry H. Johnston. From the Smithsonian Report for 1901, pages 661–666, with Plates I–III. Washington: Government Printing Office, 1902. Octavo.

1360. Observations on Termites, or Mixed Ants, by G. D. Haviland. From the Smithsonian Report for 1901, pages 667–678, with Plates I–IV. Washington: Government Printing Office, 1902. Octavo.

1361. The Wanderings of the Water Buffalo. From the Smithsonian Report for 1901, pages 679–682, with Plate I. Washington: Government Printing Office: 1902. Octavo.

1362. On the Preservation of the Marine Animals of the Northwest Coast, by William H. Dall. From the Smithsonian Report for 1901, pages 683–688. Washington: Government Printing Office, 1902. Octavo.

1363. Some Private Zoos, by F. G. Aflalo. From the Smithsonian Report for 1901, pages 689–696, with Plates I–VII. Washington: Government Printing Office, 1902. Octavo.

1364. The National Zoo at Washington, by Ernest Thompson Seton. From the Smithsonian Report for 1901, pages 697–716, with Plates I–XIII. Washington: Government Printing Office, 1902. Octavo.

1365. The Submarine Boat, by Rear-Admiral George W. Melville, U. S. Navy. From the Smithsonian Report for 1901, pages 717–738, with Plates I, II. Washington: Government Printing Office, 1902. Octavo.

1366. Commemoration of Prof. Henry A. Rowland, by Dr. Thomas C. Mendenhall. From the Smithsonian Report for 1901, pages 739–753, with Plate I. Washington: Government Printing Office, 1902. Octavo.

IV. NATIONAL MUSEUM PUBLICATIONS.

1310. Annual Report of the Board of Regents of the Smithsonian Institution, showing the operations, expenditures, and condition of the Institution for the year ending June 30, 1900. Report of the United States National Museum. Washington: Government Printing Office, 1902. Octavo, pages XVI+738, with 122 plates.

1310 (1). Report upon the Condition and Progress of the United States National Museum during the year ending June 30, 1900, by Richard Rathbun, Assistant Secretary of the Smithsonian Institution. From the Report of the United States National Museum for 1900, pages 1–152, with 9 plates. Washington: Government Printing Office, 1902. Octavo.

R. S. 116. Anthropological Studies in California, by William Henry Holmes, Head Curator, Department of Anthropology. From the Report of the United States National Museum for 1900, pages 155–187, with 50 plates. Washington: Government Printing Office, 1902. Octavo.

R. S. 117. Aboriginal American Harpoons. A Study in Ethnic Distribution and Invention, by Otis Tufton Mason, curator, Division of Ethnology. From the Report of the United States National Museum for 1900, pages 189–304, with 20 plates. Washington: Government Printing Office, 1902. Octavo.

R. S. 118. A sketch of the History of Ceramic Art in China, with a Catalogue of the Hippisley Collection of Chinese Porcelains, by Alfred E. Hippisley, commissioner of the imperial maritime customs service of China. From the Report of the United States National Museum for 1900, pages 305–416, with 21 plates. Washington: Government Printing Office, 1902. Octavo.

R. S. 119. Contributions to the History of Musical Scales, by Charles Kasson Wead, examiner, United States Patent Office. From the Report of the United States National Museum for 1900, pages 417–462, with 10 plates. Washington: Government Printing Office, 1902. Octavo.

R. S. 120. A Collection of Hopi Ceremonial Pigments, by Walter Hough. From the Report of the United States National Museum for 1900, pages 463–471. Washington: Government Printing Office, 1902. Octavo.

R. S. 121. Descriptive Catalogue of the Collections of Gems in the United States National Museum, by Wirt Tassin, assistant curator, Division of Mineralogy. From the Report of the United States National Museum for 1900, pages 473–670, with 9 plates. Washington: Government Printing Office, 1902. Octavo.

R. S. 122. Descriptive Catalogue of the Meteorite Collection in the United States National Museum, to January 1, 1902, by Wirt Tassin, assistant curator, Division of Mineralogy. From the Report of the United States National Museum for 1900, pages 671–698, with 4 plates. Washington: Government Printing Office, 1902. Octavo.

Proceedings of the United States National Museum, Vol. XXIII, published under the direction of the Smithsonian Institution. Washington: Government Printing Office, 1901. Octavo. Pages xv, 952, with 44 plates.

The following separate papers from the Proceedings were issued during the fiscal year:

Proc. 1235. List of Fishes Collected in 1883 and 1885 by Pierre Louis Jouy and Preserved in the United States National Museum, with Descriptions of Six New Species, by David Starr Jordan and John Otterbein Snyder. From the Proceedings of the United States National Museum, Vol. XXIII, pages 739–769, with Plates XXXI–XXXVIII. Washington: Government Printing Office, 1901. Octavo.

Proc. 1236. Four New Symmetrical Hermit Crabs (Pagurids) from the West India Region, by James E. Benedict. From the Proceedings of the United States National Museum, Vol. XXIII, pages 771–778. Washington: Government Printing Office, 1901. Octavo.

Proc. 1237. Synopsis of the Lucinacea and of the American Species, by William Healey Dall. From the Proceedings of the United States National Museum, Vol. XXIII, pages 779–833, with Plates XXXIX–XLII. Washington: Government Printing Office, 1901. Octavo.

Proc. 1238. On a Slug of the Genus Veronicella from Tahiti, by T. D. A. Cockerell. From the Proceedings of the United States National Museum, Vol. XXIII, pages 835–836. Washington: Government Printing Office, 1901. Octavo.

Proc. 1239. A Review of the Apodal Fishes or Eels of Japan, with Descriptions of Nineteen New Species, by David Starr Jordan and John Otterbein Snyder. From the Proceedings of the United States National Museum, Vol. XXIII, pages 837–890. Washington: Government Printing Office, 1901. Octavo.

Proc. 1240. A Review of the Cardinal Fishes of Japan, by David Starr Jordan and John Otterbein Snyder. From the Proceedings of the United States National Museum, Vol. XXIII, pages 891–913, with Plates XLIII–XLIV. Washington: Government Printing Office, 1901. Octavo.

Proc. 1241. A Review of the Hypostomide and Lophobranchiate Fishes of Japan, by David Starr Jordan and John Otterbein Snyder. From the Proceedings of the United States National Museum, Vol. XXIV, pages 1–20, with Plates I–XII. Washington: Government Printing Office, 1901. Octavo.

Proc. 1242. List of the Myriapod Family Lithobidæ of Salt Lake County, Utah, with Descriptions of Five New Species, by Ralph V. Chamberlin. From the Proceedings of the United States National Museum, Vol. XXIV, pages 21–25. Washington: Government Printing Office, 1901. Octavo.

Proc. 1243. New Diptera from Southern Africa, by D. W. Coquillett. From the Proceedings of the United States National Museum, Vol. XXIV, pages 27–32. Washington: Government Printing Office, 1901. Octavo.

Proc. 1244. A Review of the Gobioid Fishes of Japan, with Descriptions of Twenty-one New Species, by David Starr Jordan and John Otterbein Snyder. From the Proceedings of the United States National Museum, Vol. XXIV, pages 33–132. Washington: Government Printing Office, 1901. Octavo.

Proc. 1245. A Flightless Auk, Mancalla californiensis, from the Miocene of California, by Frederic A. Lucas. From the Proceedings of the United States National Museum, Vol. XXIV, pages 133–134. Washington: Government Printing Office, 1901. Octavo.

Proc. 1246. An Annotated List of Mammals Collected in the Vicinity of La Guaira, Venezuela, by Wirt Robinson, captain, U. S. Army, and Marcus Ward Lyon, jr. From the Proceedings of the United States National Museum, Vol. XXIV, pages 135–162. Washington: Government Printing Office, 1901. Octavo.

Proc. 1247. An Annotated List of Birds Collected in the Vicinity of La Guaira, Venezuela, by Wirt Robinson, captain, U. S. Army, and Charles W. Richmond. From the Proceedings of the United States National Museum, Vol. XXIV, pages 163–178. Washington: Government Printing Office, 1901. Octavo.

Proc. 1248. An Annotated List of Batrachians and Reptiles Collected in the Vicinity of La Guaira, Venezuela, with Descriptions of Two New Species of Snakes, by Leonhard Stejneger. From the Proceedings of the United States National Museum, Vol. XXIV, pages 179–192. Washington: Government Printing Office, 1901. Octavo.

Proc. 1249. On a Stony Meteorite, which Fell near Felix, Perry County, Alabama, May 15, 1900, by George P. Merrill. From the Proceedings of the United States National Museum, Vol. XXIV, pages 193–198, with Plates XIII–XIV. Washington: Government Printing Office, 1901. Octavo.

Proc. 1250. A Review of the Atherine Fishes of Japan, by David Starr Jordan and Edwin Chapin Starks. From the Proceedings of the United States National Museum, Vol. XXIV, pages 199–206. Washington: Government Printing Office, 1901. Octavo.

Proc. 1251. The Cacomitl Cat of the Rio Grande Valley, by Edgar A. Mearns. From the Proceedings of the United States National Museum, Vol. XXIV, pages 207–210. Washington: Government Printing Office, 1901. Octavo.

Proc. 1252. A New Species of Bullfrog from Florida and the Gulf Coast, by Leonhard Stejneger. From the Proceedings of the United States National Museum, Vol. XXIV, pages 211–215. Washington: Government Printing Office, 1901. Octavo.

Proc. 1253. Some Spiders and Other Arachnida from Porto Rico, by Nathan Banks. From the Proceedings of the United States National Museum, Vol. XXIV, pages 217–227, with Plate XV. Washington: Government Printing Office, 1901. Octavo.

Proc. 1254. A Review of the Gymnodont Fishes of Japan, by David Starr Jordan and John Otterbein Snyder. From the Proceedings of the United States National Museum, Vol. XXIV, Pages 229–264. Washington: Government Printing Office, 1901. Octavo.

Proc. 1255. Two New Species of Algæ of the Genus Buthotrephis, from the Upper Silurian of Indiana, by David White. From the Proceedings of the United States National Museum, Vol. XXIV, pages 265–270, with Plates XVI–XVIII. Washington: Government Printing Office, 1901. Octavo.

Proc. 1256. The Fossil Fresh-Water Shells of the Colorado Desert, Their Distribution, Environment, and Variation, by Robert E. C. Stearns. From the Proceedings of the United States National Museum, Vol. XXIV, pages 271–299, with Plates XIX-XXIV. Washington: Government Printing Office, 1901. Octavo.

Proc. 1257. Chondrodonta, a New Genus of Ostreiform Mollusks from the Cretaceous, with Descriptions of the Genotype and a New Species, by Timothy W. Stanton. From the Proceedings of the United States National Museum, Vol. XXIV, pages 301–307, with Plates XXV–XXVI. Washington: Government Printing Office, 1901. Octavo.

Proc. 1258. Catalogue of a Collection of Hummingbirds from Ecuador and Colombia, by Harry C. Oberholser. From the Proceedings of the United States National Museum, Vol. XXIV, pages 309–342. Washington: Government Printing Office, 1902. Octavo.

Proc. 1259. A Review of the Discobolous Fishes of Japan, by David Starr Jordan and John Otterbein Snyder. From the Proceedings of the United States National Museum, Vol. XXIV, pages 343–351. Washington: Government Printing Office, 1902. Octavo.

Proc. 1260. A Review of the Japanese Species of Surf-Fishes or Embiotocidæ, by David Starr Jordan (assisted by Michitaro Sindo). From the Proceedings of the United States National Museum, Vol. XXIV, pages 353–359. Washington: Government Printing Office, 1902. Octavo.

Proc. 1261. A Review of the Pediculate Fishes or Anglers of Japan, by David Starr Jordan (assisted by Michitaro Sindo). From the Proceedings of the United States National Museum, Vol. XXIV, pages 361–381. Washington: Government Printing Office, 1902. Octavo.

Proc. 1262. Descriptions of New American Butterflies, by William Schaus. From the Proceedings of the United States National Museum, Vol. XXIV, pages 383–460. Washington: Government Printing Office, 1902. Octavo.

Proc. 1263. A Review of the Trachinoid Fishes and Their Supposed Allies Found in the Waters of Japan, by David Starr Jordan and John Otterbein Snyder. From the Proceedings of the United States National Museum, Vol. XXIV, pages 461–497. Washington: Government Printing Office, 1902. Octavo.

Proc. 1264. Illustrations and Descriptions of New, Unfigured, or Imperfectly Known Shells, Chiefly American, in the United States National Museum, by William Healey Dall. From the Proceedings of the United States National Museum, Vol. XXIV, pages 499–566, with Plates XXVII–XL. Washington: Government Printing Office, 1902. Octavo.

Proc. 1265. A Review of the Salmonoid Fishes of Japan, by David Starr Jordan and John Otterbein Snyder. From the Proceedings of the United States National Museum, Vol. XXIV, pages 567–593. Washington: Government Printing Office, 1902. Octavo.

Proc. 1266. A Review of the Labroid Fishes and Related Forms found in the Waters of Japan, by David Starr Jordan and John Otterbein Snyder. From the Proceedings

of the United States National Museum, Vol. XXIV, pages 595–662. Washington: Government Printing Office, 1902. Octavo.

Proc. 1267. List of Generic Terms Proposed for Birds during the Years 1890 to 1900, Inclusive, to which are Added Names Omitted by Waterhouse in his "Index Generum Avium," by Charles W. Richmond. From the Proceedings of the United States National Museum, Vol. XXIV, pages 663–729. Washington: Government Printing Office, 1902. Octavo.

Proc. 1268. A Review of the American Moths of the Genus Depressaria Haworth, with Descriptions of New Species, by August Busck. From the Proceedings of the United States National Museum, Vol. XXIV, pages 731–749. Washington: Government Printing Office, 1902. Octavo.

Proc. 1269. The Mammals of the Andaman and Nicobar Islands, by Gerrit S. Miller, jr. From the Proceedings of the United States National Museum, Vol. XXIV, pages 751–795, with Plates XLI–XLII. Washington: Government Printing Office, 1902. Octavo.

Proc. 1270. Henicops dolichopus, A New Chilopod from Utah, by Ralph V. Chamberlin. From the Proceedings of the United States National Museum, Vol. XXIV, pages 797–800. Washington: Government Printing Office, 1902. Octavo.

Proc. 1271. A Review of the Larks of the Genus Otocoris, by Harry C. Oberholser. From the Proceedings of the United States National Museum, Vol. XXIV, pages 801–883, with Plates XLIII–XLIX. Washington: Government Printing Office, 1902. Octavo.

Proc. 1272. Descriptions of New Decapod Crustaceans from the West Coast of North America, by Mary J. Rathbun. From the Proceedings of the United States National Museum, Vol. XXIV, pages 885–905. Washington: Government Printing Office, 1902. Octavo.

Proc. 1273. A Newly Found Meteorite from Admire, Lyon County, Kansas, by George P. Merrill. From the Proceedings of the United States National Museum, Vol. XXIV, pages 907–913, with Plates L–LVI. Washington: Government Printing Office, 1902. Octavo.

Proc. 1274. Descriptions of Three New Birds from the Southern United States, by Edgar A. Mearns. From the Proceedings of the United States National Museum, Vol. XXIV, pages 915–926. Washington: Government Printing Office, 1902. Octavo.

Directions for Preparing Study Specimens of Small Mammals, by Gerrit S. Miller, jr., assistant curator, division of mammals. Part N of Bulletin of the United States National Museum, No. 39. Second edition, revised, with abstracts in German, French, and Spanish. Washington: Government Printing Office, 1901. Octavo, pages 25.

Directions for Collectors of American Basketry, by Otis T. Mason, curator, division of ethnology. Part P of Bulletin of the United States National Museum, No. 39. Washington: Government Printing Office, 1902. Octavo, pages 31.

Bulletin of the United States National Museum, No. 50. The Birds of North and Middle America, by Robert Ridgway, curator, division of birds. Part I. Washington: Government Printing Office, 1901. Octavo, pages XXX+715, with 20 plates.

Bulletin of the United States National Museum, No. 51. A list of the Publications of the United States National Museum, by Randolph I. Geare, chief of correspondence and documents. Washington: Government Printing Office, 1902. Octavo, pages VII+168.

V. PUBLICATIONS OF THE ASTROPHYSICAL OBSERVATORY.

A second edition of Volume I of the Annals of the Astrophysical Observatory was printed during the year from the stereotype plates as corrected for the following Senate document, of which it formed a part: Senate Document No. 20, Fifty-seventh Congress, first session. Report of the Secretary of the Smithsonian Institution of

all appropriations heretofore expended by the Astrophysical Observatory, results reached, and present condition of the work. In response to Senate resolution of February 25, 1901. Washington: Government Printing Office, 1902. Quarto, pages XXXIII+308, with 44 plates.

VI. PUBLICATIONS OF THE BUREAU OF AMERICAN ETHNOLOGY.

Eighteenth Annual Report of the Bureau of American Ethnology to the Secretary of the Smithsonian Institution. 1896–97. By J. W. Powell, Director. In two parts. Part II. Washington: Government Printing Office, 1899. Imperial octavo, pp. 521–997, with 67 plates. *Contents:* Indian Land Cessions in the United States. Compiled by Charles C. Royce, with an introduction by Cyrus Thomas.

The separate papers of Part I of the Nineteenth Annual Report were received from the printer and distributed before the close of the fiscal year, but the bound volume was not completed. The two parts of this report comprise the following papers:

Report of the Director, pages XI–XCII, frontispiece.

Myths of the Cherokee, by James Mooney, pages 3–548, plates I–XX, figures 1–2.

Tusayan Migration Traditions, by J. W. Fewkes, pages 573–634.

Localization of Tusayan Clans, by Cosmos Mindeleff, pages 635–653, plates XXI–XXVIII, figure 3.

Mounds in Northern Honduras, by Thomas Gann, pages 655–692, plates XXIX–XXXIX, figures 4–7.

Mayan Calendar Systems, by Cyrus Thomas, pages 693–819, plates XL–XLIV, figures 8–22.

Primitive Numbers, by W J McGee, pages 821–851.

Numeral Systems of Mexico and Central America, by Cyrus Thomas, pages 853–955, figures 23–41.

Tusayan Flute and Snake Ceremonies, by J. W. Fewkes, pages 957–1011, plates XLV–LXV, figures 42–46.

The Wild Rice Gatherers of the Upper Lakes, by A. E. Jenks, pages 1013–1137, plates LXVI–LXXIX, figures 47–48.

Bulletin 26. Kathlamet Texts, by Franz Boas. Washington: Government Printing Office, 1901. Octavo, pages 261, with 1 plate.

VII. PUBLICATIONS OF AMERICAN HISTORICAL ASSOCIATION.

The Annual Report of the American Historical Association for the year 1901 was sent to the printer toward the close of the fiscal year, and most of it was in type before June 30. The report is in two volumes, with the following contents:

Volume I: Report of Proceeding of Seventeenth Annual Meeting at Washington, D. C., December 27–31, 1901, by Charles H. Haskins, corresponding secretary; An Undeveloped Function, Inaugural address by President Charles Francis Adams; The Massachusetts Public Record Commission and its Work, by Robert T. Swan; The Relation of the National Library to Historical Research in the United States, by Herbert Putnam, Librarian of Congress; The Sandemanians of New England, by Prof. Williston Walker; James Madison and Religious Liberty, by Gaillard Hunt; The Chronology of the Erasmus Letters, by Prof. Ephraim Emerton; Moses Coit Tyler, by Prof. George L. Burr; Herbert B. Adams, by Prof. John M. Vincent; Maryland's First Courts, by Dr. Bernard C. Steiner; Southwestern History in the Southwest, by Prof. George P. Garrison; Committees of Correspondence of the American Revolution, by Dr. Edward D. Collins; Jay's Treaty and the Slavery Interests of the United States, by Frederic Austin Ogg; The Legislative History of Naturalization in the United States, 1776–1795, by F. G. Franklin; The Influence of

Party upon Legislation in England and America, by Prof. A. Lawrence Lowell (with four diagrams); London Company Records, by President Lyon G. Tyler; The Relation between the Virginia Planter and the London Merchant, by Prof. John S. Bassett; Index.

Volume II: Georgia and State Rights, prize essay by Ulrich Bonnell Phillips; Report of the Public Archives Commission.

VIII. NATIONAL SOCIETY OF THE DAUGHTERS OF THE AMERICAN REVOLUTION.

The fourth report of the Society was received and submitted to Congress.

Respectfully submitted.

A. HOWARD CLARK, *Editor.*

Mr. S. P. LANGLEY,
Secretary Smithsonian Institution.

AUGUST 1, 1902.

Appendix VIII.

REPORT OF THE REPRESENTATIVE OF THE SMITHSONIAN INSTITUTION AND NATIONAL MUSEUM, PAN-AMERICAN EXPOSITION, BUFFALO, NEW YORK, 1901.

Sir: I have the honor to submit the following report on the Pan-American Exposition, held at Buffalo, N. Y., from May 1, 1901, to November 2, 1901, inclusive:

Participation in this exposition by the Smithsonian Institution and National Museum was provided for in the act of Congress, approved March 3, 1899, appropriating the sum of $200,000 for a Government building and the sum of $300,000 for a Government exhibit. Of the latter sum $50,000 was allotted to the Institution and Museum, and $2,500 was transferred from the allotment of the Interior Department for the joint preparation of a restoration of the gigantic extinct American reptile known as *Triceratops*. Subsequently the Smithsonian allotment was assessed $1,960.79 for a general exhibit from the Philippine Islands to be prepared under the supervision of a special committee of Government board, and $200 was transferred to the allotment of the War Department. The net Smithsonian allotment was, therefore, $50,339.21.

All the dependencies of the Institution were represented by separate displays except the Bureau of American Ethnology, which cooperated with the Department of Anthropology in the National Museum.

The space in the Government building assigned to the Institution and Museum was at the northwest corner and comprised about 7,500 square feet, having a frontage on the main aisle of about 133 feet and a depth of 56 feet.

The act of Congress providing for the Government exhibit stipulated that it should comprise "such articles and material as illustrate the function and administrative faculty of the Government in time of peace and * * * tending to demonstrate the nature of our institutions and their adaptation to the wants of the people." Following out the spirit of the law, the exhibits of the Institution and Museum were planned to show their scope and methods of work, and at the same time to indicate their resources.

In the case of the National Museum such topics were chosen for illustration as were germane to the central idea of the exposition, namely, a display of the products of nature and the works of man in the Western Hemisphere. The Museum on this occasion, as previously, prepared much larger exhibits than the other bureaus of the Institution, on account of its peculiar functions and resources which fit it to participate extensively in enterprises of this kind. The displays of the other bureaus were necessarily limited, for the most part, to such pictures, models, and publications as would serve to indicate the material with which and the conditions under which their work is carried on, and some of the results of their activities.

SMITHSONIAN INSTITUTION PROPER.

The work of the Smithsonian Institution covers fields more varied than is generally supposed. It may be a surprise to many to know that by the Congressional act of its foundation it is devoted primarily to art and only secondarily to science. One of its interests, which has not hitherto been presented in a temporary exposition, is the fostering of art. To impress on the minds of the public the fact that this is a

feature of the work of the Institution, two series of reproductions of paintings were exhibited, one representing the history of painting and the second the history of portraiture. These two important topics could be illustrated only in outline on account of limited space, but the series included reproductions of a considerable number of the greatest paintings and portraits of all epochs and schools.

In addition, the exhibit of the Institution included a complete set of its publications and those of its bureaus; portraits of the secretaries; personal relics of James Smithson; a cast of the bronze tablet recently placed on the tomb of Smithson at Genoa, Italy; a copy of the seal of the Institution; objects and papers relating to the Hodgkins fund, including publications, medals, and a portrait of the founder, Thomas G. Hodgkins; two large photographs of the ærodrome of Secretary Langley; a picture of the Smithsonian building; and copies of the history of the first half century of the Smithsonian Institution.

The exhibit of the Institution was installed in the extreme northwest corner of the building. It was assembled, under the direction of the Secretary, by Dr. Richard Rathbun, Assistant Secretary.

BUREAU OF AMERICAN ETHNOLOGY.

As already stated, this Bureau made no separate exhibit at Buffalo, but coöperated with the department of anthropology of the National Museum. Dr. W J McGee, of the Bureau of American Ethnology, made an expedition to Sonora, Mexico, for the purpose of obtaining a collection representing the arts of the Seri Indians. On reaching their country, however, he found that the tribe was exterminated, and he then turned his attention to the Cocopa Indians, from whom he obtained an important collection.

NATIONAL ZOÖLOGICAL PARK.

The chief exhibit of the park was an elaborate relief model showing the topographical features of the grounds and the location of the animal houses, paddocks, ranges, and cages. This was supplemented by photographs of some of the principal houses and of picturesque points in the park.

BUREAU OF INTERNATIONAL EXCHANGES.

It will be appreciated that the work of the Bureau of Exchanges does not lend itself to exhibition by material objects. The exhibit at Buffalo consisted of a set of Government publications such as are distributed annually to other governments throughout the world, and a series of photographs showing the interior of the offices of the Bureau in Washington and the receipt and dispatch of consignments of scientific publications.

ASTROPHYSICAL OBSERVATORY.

The exhibit of this Bureau was selected and prepared, under the direction of the Secretary of the Institution.

The principal object in the exhibit was a photograph of the infra-red end of the solar spectrum, showing the work of the Observatory on this subject for a period of years. The photograph was enlarged so as to have a length of about 20 feet, and was displayed on the north wall. There was also exhibited a series of photographs of the solar eclipse, as observed at Waynesboro, N. C.

In a table case near by was shown a copy of Volume I of the *Annals of the Astrophysical Observatory*, a new serial publication containing the results of the work of the Observatory. The following objects were also exhibited: The bolometer, or electric thermometer, an extremely sensitive instrument, the invention of Mr. Langley, used in measuring the heat of the invisible spectrum of the sun, the temperature of the stars, etc.; photographs of other instruments used in the Observatory, such as the siderostat, galvanometer, and spectrometer; photographs of the exterior and interior of the Observatory buildings in the Smithsonian grounds.

NATIONAL MUSEUM.

The exhibit of the National Museum, as on previous occasions, occupied very much more space than those of the other bureaus of the Institution.

It was planned to show the scope and methods of the Museum and at the same time to illustrate as far as practicable some topic germane to the general idea of the exposition implied in the name Pan-American. The three administrative departments made separate exhibits, but the lines of separation between the various subdivisions in these departments were not recognized in every instance.

Department of Anthropology.—The exhibit of this department of the Museum was planned and prepared by Mr. W. H. Holmes, head curator, assisted by the scientific staff. It occupied the south end of the Museum space.

This exhibit was planned with the view of representing the various aboriginal peoples of America and the material products of their activities.

Groups of lay figures.—Twelve of these groups were exhibited, each representing a family (man, woman, and children), and each with an appropriate setting, indicating customs, arts, and general environment. Many of the figures were prepared especially for this exposition by skilled sculptors and preparators, under the personal direction of the head curator, and were the best objects of the kind the Museum has ever exhibited. The two largest groups—those of the Greenland Eskimo and Patagonians—occupied cases 12 feet long and 8 feet wide. The other 10 groups were somewhat smaller. A complete list is as follows: (1) North Greenland Eskimo; (2) Eastern Eskimo; (3) Alaskan Eskimo; (4) Chilcat Indians, Alaska; (5) Hupa Indians, California; (6) Sioux Indians of the Great Plains; (7) Navajo Indians of the arid region of the United States; (8) Zuñi Indians of the arid region; (9) Cocopa Indians, Sonora, Mexico; (10) Maya Quiche Indians, Guatemala; (11) a Zapotec Indian woman, Mexico, a Jivaro Indian man and a Piro Indian man, Brazil; (12) Tehuelche Indians, Patagonia. Nos. 2, 3, and 11 were not completed as family groups.

Dwelling group models.—This series consisted of thirteen models, each about 4 feet long and 2 feet wide, representing the houses and outbuildings and appurtenances occupied by a family or communal group. The following is a list of those models: (1) Snow houses of the Eskimo; (2) earth house of Alaskan Eskimo; (3) wooden dwellings of the northwest coast Indians; (4) skin and bark covered lodges of the Montagnais Indians, Labrador; (5) dwellings of the Sierra Digger Indians, California; (6) skin lodges of the Great Plains Indians; (7) grass houses of the Wichita Indians of Indian Territory; (8) earth lodges of the Pawnee Indians, Dakota; (9) cliff dwellings (ruins), Arizona; (10) grass and adobe houses of Papago Indians, old style, Arizona; (11) grass and adobe houses of Papago Indians, late forms; (12) pile dwellings of the Venezuela tribes; (13) skin shelters of the Patagonians.

Exhibits illustrating leading activities of American aborigines.—These exhibits, thirteen in number, were designed to show the status of various American native races as regards culture. The series presented were as follows: (1) Fire-making apparatus; (2) bows and arrows; (3) throwing sticks; (4) harpoons; (5) water craft; (6) basketry; (7) woven fabrics; (8) pottery; (9) sculpture; (10) personal-ornament necklaces; (11) tobacco pipes; (12) pictography and writing; (13) musical instruments.

These series were shown in standard Museum cases, 8½ feet long and 7 feet high, and comprised many hundred objects of importance and general interest.

Department of Biology.—The exhibit of this department of the Museum was planned and prepared by Dr. F. W. True, head curator, with the assistance of the staff of the divisions of mammals, birds, reptiles, and fishes.

The exhibit of the department was projected in harmony with the general theme of the exposition and only American animals were exhibited. As space was limited only vertebrate animals were included. In order to fill gaps in the series as far as

possible and to make the collection more significant, small collecting expeditions were sent out to Cuba, Porto Rico, Florida, and the Amazon River. These obtained many fine characteristic specimens not previously well represented in the Museum collections. The exhibit as a whole represented very satisfactorily the most important, interesting, and attractive American vertebrates, both large and small.

Mammals.—The collection of mammals included such large forms as the moose, elk, musk ox, Caribbean seal, Kodiak bear, wolf, puma, manatee, mountain sheep, mountain goat, etc. A considerable number of specimens were mounted especially for the exposition, and represented the best efforts of modern taxidermy. Several important species recently discovered, such as the Glacier bear, Kodiak bear, Stone's sheep, etc., were included in the exhibit.

Birds.—The collection of birds was the largest series displayed by the department. Such large characteristic birds as the condor, wild turkey, whooping crane, California vulture, etc., were represented by exceedingly fine specimens, mounted in the very best manner. The smaller birds included numerous species remarkable for their brilliant colors, peculiar habits, or grotesque form, and as a whole the series was calculated to give the visitor an excellent idea of the variety and beauty of the American bird fauna as a whole. An extensive collection of humming birds, an exclusively American family, was shown in a special case.

Reptiles and batrachians.—The collection of these two classes was much smaller than the others, as the Museum had no considerable exhibition series ready at hand to draw upon, and to obtain suitable material within a specified time is a matter of the greatest difficulty. The number of suitable specimens finally obtained, however, proved greater than could be accommodated in the small space which it seemed prudent at the outset of the enterprise to allot to these two classes, which space was at the last moment still further reduced to provide the necessary aisle room. Some such remarkable forms as the mata-mata tortoise and the large Amazon River tortoise, though ready for exhibition, were finally crowded out.

The exhibit included the more important American poisonous and nonpoisonous snakes, various fresh-water and land tortoises, characteristic lizards, including the large Cuban iguana, and a few toads, frogs, salamanders, and other amphibians. Among the largest specimens was a tortoise known as the alligator snapper, which is the largest of American fresh-water tortoises, and a boa constrictor.

Fishes.—The collection of American fishes was in three divisions: (1) A general series of painted casts of characteristic marine and fresh-water species; (2) a series of subtropical marine fishes from Key West, Fla., preserved in formalin; and (3) a series of the fishes of the Amazon River, also preserved in formalin. The collection included the best casts in the Museum permanent series. It is impracticable to mention the species in detail in this place, but the series as a whole was especially strong in important food and game fishes of the lakes and rivers of North America, and of the Atlantic coast, and characteristic South American species.

A special exhibit in this class consisted of an enlarged model of a remarkable phosphorescent deep-sea fish, so installed that the luminous spots in the sides and the lantern-like protuberance on the head were made to glow as in life.

The mammals exhibited by the Department of Biology were installed in two large wall cases, each 40 feet long, in the center of the Museum space, the fishes in a similar but shallow case at the west end, the birds in eight standard Museum "door-screen" cases, and the reptiles and batrachians in four standard "slope-top" cases.

A large proportion of the specimens in each of the five classes were provided with descriptive labels in nontechnical language, in which the habits and geographical range of each species were cited, together with other items of general interest.

Department of Geology.—The exhibit of this department was planned and arranged by Dr. George P. Merrill, head curator, with the assistance of the scientific staff. It occupied the north end of the Museum space.

The exhibit followed, as far as circumstances would permit, the lines of the permanent exhibition series of the Museum. Each division of the department was represented, and in addition there was included a full-sized restoration of the skeleton of the huge extinct American reptile *Triceratops*, prepared and exhibited conjointly by the Museum and the United States Geological Survey.

Division of Geology.—The display made by this division comprised three seeris, (1) a collection of rocks from the Hawaiian Islands, (2) a series of native elements, (3) a series of concretionary forms. The collection of Hawaiian rocks, which occupied one case, consisted mainly of specimens obtained by the United States Exploring Expedition in 1840, by Mr. A. B. Lyon in 1892, and Prof. C. H. Hitchcock in 1899. The rocks of these islands are all of igneous character, except the limestones of the coral reefs along the shores.

The series of native elements comprised those sixteen, such as sulphur, arsenic, gold, etc., which occur in an uncombined state in the earth's crust. The full series was as follows: Carbon, sulphur, selenium, telurium, arsenic, antimony, bismuth, gold, silver, copper, lead, mercury, platinum, iridosmine (iridium and osmium), and iron. This collection was installed in a special case, and particular care was taken with the details of mounting to emphasize its significance. Among the most interesting objects included were a very perfect crystal of diamond from South Africa (representing carbon) and a nugget of platinum from Russia weighing 444 grams.

The series of concretionary forms included specimens of orbicular granites from Rhode Island, Sweden, and Finland, and of septarian concretions of clay ironstone from New York, Kansas, and Weymouth, England, and other localities. These occupied a wall case.

Division of Mineralogy.—The exhibit of this division consisted of an extensive series of minerals, very carefully classified, arranged, and labeled to illustrate the methods employed by the Museum when exhibiting large, systematic collections. The series comprised about 500 specimens and was accompanied by 47 group labels in addition to individual labels for each specimen. It occupied four standard Museum "slope-top" floor cases.

Division of Stratigraphic Paleontology—Section of Invertebrate Fossils.—This section exhibited two series of invertebrate fossils, crinoids and cephalopods.

The crinoids, or stone lilies, were represented by specimens of 94 genera, and the cephalopods (cuttlefish, squids, etc.) by specimens of 146 genera. They were accompanied by descriptive labels, the technical terms in which were explained by a special series of specimens artificially colored to draw attention to the particular parts referred to. The collection was installed in five standard Museum "door screen" cases.

Section of Vertebrate Fossils.—On account of the limited space, but few vertebrate fossils could be exhibited. The exhibit consisted of a full-size restoration of the skeleton of the Tertiary American reptile, *Triceratops*, mention of which has already been made; a skeleton of a cretaceous fossil toothed bird, *Hesperornis;* a restoration of the skeleton of *Zeuglodon*, an extinct whale-like mammal from the Eocene, and bones and skulls of the mastodon, mammoth, and titanotherium.

In the case of *Triceratops*, a small model and painting showing the probable external appearance of the animal were exhibited with the restoration of the skeleton, and a large oil painting representing the creature in its native fields was displayed on an adjacent wall.

Dr. F. W. True, representative for the Institution and Museum on the Government board, was also chairman of the special committee on exhibits from the Outlying Possessions of the United States. Mr. W. V. Cox, chief special agent, was also secretary of the Government board.

Summary of allotments made to the Smithsonian Institution.

Original allotment		$50,000.00
Transfer from the Interior Department allotment		2,500.00
Gross allotment		52,500.00
Transfer to the allotment for Philippine exhibit	$1,960.79	
Transfer to War Department allotment	200.00	
		2,160.79
Net allotment		50,339.21

Classified statement of expenditures of the funds allotted to the Smithsonian Institution.

Services of mechanics and laborers and care of exhibits		$9,221.47
Services of clerks and assistants		3,484.50
Travel and subsistence (Washington and Buffalo):		
Railroad fares	$1,131.95	
Sleeping-car fares	228.50	
Incidental traveling expenses	60.85	
Per diem allowances in lieu of subsistence	1,961.25	
		3,382.55
Freight, cartage, and expressage		1,264.52
Specimens and construction of exhibits for National Museum (including materials, services, field expenses, etc.)		26,148.53
Supplies (hardware, glass, and lumber for cases; packing material, etc.)		5,027.15
Office and miscellaneous expenses		1,757.90
		50,286.62
Unexpended balance		52.59
		50,339.21

Statement corrected to March 8, 1902.
Respectfully submitted.

FREDERICK W. TRUE,
Representative Smithsonian Institution and United States National Museum, Pan-American Exposition.

Mr. S. P. LANGLEY,
Secretary of the Smithsonian Institution.

JUNE 18, 1902.

GENERAL APPENDIX

TO THE

SMITHSONIAN REPORT FOR 1902.

ADVERTISEMENT.

The object of the GENERAL APPENDIX to the Annual Report of the Smithsonian Institution is to furnish brief accounts of scientific discovery in particular directions; reports of investigations made by collaborators of the Institution; and memoirs of a general character or on special topics that are of interest or value to the numerous correspondents of the Institution.

It has been a prominent object of the Board of Regents of the Smithsonian Institution, from a very early date, to enrich the annual report required of them by law with memoirs illustrating the more remarkable and important developments in physical and biological discovery, as well as showing the general character of the operations of the Institution; and this purpose has, during the greater part of its history, been carried out largely by the publication of such papers as would possess an interest to all attracted by scientific progress.

In 1880 the Secretary, induced in part by the discontinuance of an annual summary of progress which for thirty years previous had been issued by well-known private publishing firms, had prepared by competent collaborators a series of abstracts, showing concisely the prominent features of recent scientific progress in astronomy, geology, meteorology, physics, chemistry, mineralogy, botany, zoology, and anthropology. This latter plan was continued, though not altogether satisfactorily, down to and including the year 1888.

In the report for 1889 a return was made to the earlier method of presenting a miscellaneous selection of papers (some of them original) embracing a considerable range of scientific investigation and discussion. This method has been continued in the present report for 1902.

RECENT AERONAUTICAL PROGRESS, AND DEDUCTIONS TO BE DRAWN THEREFROM, REGARDING THE FUTURE OF AERIAL NAVIGATION.[a]

By Maj. B. F. S. Baden-Powell.

It is with feelings of the greatest satisfaction that I am now able for the first time to address the society in the capacity of its president, and I must seize this opportunity of expressing to you my heartfelt thanks for the very great honor which you have conferred upon me by electing me to this position. I can not but feel that my labors in the past, though varied and dipping into almost every branch of aeronautics, have not been so extensive or so prominent as to warrant my selection for this important post, but nevertheless I sincerely hope that, with freer opportunities, I may, in the immediate future, be able to accomplish much more in the work we have before us.

My absence from England during the last three years, on active service in South Africa, has prevented my fulfilling many important duties for the society during a period of unusual activity and importance, but, on the other hand, the time I have spent on the "trackless veldt," and in the monotony of camp life, has not, I hope, been wasted, as ample opportunity has been afforded for careful meditation and consideration of the whole subject which it is the object of this society to study. I therefore propose not so much to give a technical lecture on the various experiments of recent years—you have had better opportunities than I of studying these—as to endeavor to make clear our present position.

During these three years many great events have taken place in the aeronautical world. Count Zeppelin's monster air ship, built on sound scientific principles, of enormous size and quite different in design to anything made before, has been completed, and has made successful ascents, although, I much regret to have to add, has not succeeded in traveling through the air at a sufficient speed to warrant its being considered a practical success.

[a] Presidential address before the Aeronautical Society of Great Britain, London, December 4, 1902. Reprinted by permission of the author and the Society from the Aeronautical Journal, No. 25, Vol. VII, January, 1903.

Then we come to M. Santos-Dumont's many more or less successful trips in his navigable balloons, which, if not demonstrating any new principles, has shown what perseverance and attention to detail can achieve. Though we have learned some useful practical lessons, and have been given data of great value for future experimenting, unfortunately the actual results attained carry us so little beyond what was accomplished twenty years before by MM. Renard and Krebs that one begins to think whether we have not nearly reached the end of the tether as regards the propulsion of balloons.

The unfortunate calamities to M. Severo's and more recently to M. de Bradsky's balloons, as well as the absolute failure of M. Roze and others, only tend to confirm this growing opinion. The latest accounts of M. Lebaudy's balloon seem to make out that it has accomplished more, but we must await the results of more prolonged trials before we can come to any decision. Mr. Stanley Spencer's trip over London in a navigable balloon, though it proved nothing as regards the dirigibility or inherent speed of the machine, attracted some interest in the matter.

Besides these we have heard of various experiments with flying machines proper. Herr Kress is said to have risen off the surface of the water, but owing to some mismanagement the machine turned downwards and fell in the water again. In Australia Mr. Hargrave has constructed a large machine. In America Mr. Wilbur Wright and his brother have been making wonderful progress with gliding machines, and Professor Langley has been hard at work constructing a large new machine. He informed me the other day that in a very short time we might expect to hear something of this—something big. It might, he added, be a big smash! But he wisely intends trying it over water.

Then, too, like the invisible universe of dark stars that Sir Robert Ball talks about as being possibly more extensive than that of those seen, there are probably more inventions being worked at in private than we ever hear of publicly, and many of them are doubtless of great importance. It is only recently that the results have been published of the valuable experiments with aerial-screw propellers which Mr. W. G. Walker conducted for Mr. Alexander.

Another sign of progress in the subject of aeronautics during the last few years has been the establishment in England of two more public bodies, the Aero Club and the Aeronautical Institute, the former having been established for the encouragement of ballooning (and possibly flying) as a sport, while the latter aims at interesting the working classes in the subject.

I may here seize the opportunity of explaining to our visitors and others the objects of our society, and why it is that we make so much of a study which to them may seem somewhat chimerical and of no

very special merit, and by explaining these I hope to enlist their sympathy and support to the movement. For I have before now been asked: "Why should it be necessary to have a society for the study of aerial navigation? Where is the importance of it? Why not institute a society for submarine navigation, for wireless telegraphy, or for the encouragement of any other novel invention for the improvement of means of communication or warfare?" But useful as many such inventions may be, none can have the great importance which may some day be attached to the machine which navigates the air.

And there are two reasons why this subject is a large one. The first is that the science of aeronautics is one combining many branches and spreads into many ramifications. We have aerial machines as they exist to-day. The balloon, forming a unique and fascinating mode of travel, enables us to mount high into the skies to obtain glorious views of earth and cloudscape, giving us a laboratory for the study of many intricate problems of the atmosphere, and forming a valuable instrument of war. We must study how this passive buoy may be improved upon, what new materials may be applied to its construction, gases, methods for causing it to rise and sink, and means of directing it out of the course of the wind. But we also have the more difficult problem of how to drive it through the air so as to make it independent of the wind and go in any desired direction. Closely connected with this is is the subject of kite flying, whether for man lifting or meteorological observation, of parachutes, and of soaring machines. All these necessitate a certain knowledge of the various branches of meteorology, which is to aeronautics as hydrogaphy is to marine navigation. Then we have the study of birds and other flying animals as a natural sequel to the science.

The second reason for the importance of this subject is the vast future which appears open to it. If such an apparatus can be constructed as will enable man to make practical use of the highway of the air, there is promise of the subject becoming of even more importance than marine navigation or railways.

We have, then, not merely to consider the broad principles of the general form of the aerial machine of the future—whether it is to take the shape of an artificial bird, a propelled kite, or a dirigible balloon. We have to study the subject of aerodynamics, the effect of air pressures on plane or curved surfaces traveling at various speeds and at various angles of incidence. We have to investigate the efficiency of aerial propellers of different forms, the strengths of materials, the energy and weights of various forms of motors. Then we must also study the natural currents of air, the variability of air strata, the trends of winds, and so on.

The great range of subjects to be gone into by our society is thus patent. Many of our members and others are busily at work in some

particular groove, making steady progress in building up their portion of the foundation of that great structure which we all hope to see rise up in the future.

But to return to the question of the recent progress in aerial navigation, I will now endeavor to point out and explain the present position we hold, and by considering the state of the subject as it at present exists to judge whether or not there is any real probability of our attaining that great goal which most of us look forward to.

Though it is improbable there are many here present to-night who do not look forward with feelings of confidence that artificial flight will some day be accomplished, yet there are still some few skeptics (most, if not all, of whom have never looked deeply into the subject) who believe it impossible. For this reason it may not perhaps be out of place in such an address as this to point out our reasons for maintaining this belief.

The first great argument in favor of it is that birds fly. If we had never seen such a thing as a bird, many of us might reasonably argue the thing to be impossible. But there they are. Not only can they rise in the air, not only progress at a very rapid rate through it, but they can continue the movement for long periods and in almost any weather. It is quite certain now that birds do not possess any very extraordinary power; but if they did we could probably "go one better" with the modern very compact and light oil engines. We have now compressed the strength of a horse into a little motor weighing no more than a large bird. There is the power. Can it be applied? Many people have argued that the flight of a bird is dependent on some valvular action of its feathers. Let it be so; but how do you account for the flight of the bat and of the flying fox? Others have thought that flight is only possible up to a certain weight, maintaining that the ostrich and the emu are beyond that limit. But geologists will point you out the fossil remains of a huge reptile which they declare flew in the air and weighed far more.

But, leaving nature, we may consider what has been done by man to justify our hopes.

Though I believe it may be said that nearly all the authorities on the subject are now of opinion that the balloon can not be considered as much more than an aid—to act as a stepping stone—to true flight, yet there are many workers who consider that very much may be accomplished by propelled balloons. Some authorities have calculated that a speed of 44 miles an hour might be practically attained, but not more.

M. Santos Dumont and others have shown us what can be done with a little cigar-shaped balloon. They have clearly demonstrated the difficulties to be overcome. It is very palpable that the surface of such a balloon must be stiff and rigid. Once it gets flabby it can not

be propelled the skin will vibrate and add to the resistance; the nose, unless distended by framework, will be driven in and offer great resistance; the gas will be driven back toward the after end, and the balance be disturbed. To preserve this necessary rigidity all the earlier navigable balloons were kept taut by means of the ballonet, but Count Zeppelin effected this by an internal framework.

Count Zeppelin, as I have said, struck out a new line. By greatly increasing the size of the balloon, he had obtained so much more lifting power as to be able to add a complete framework that stiffened it. But it was probably solely owing to this great size that the apparatus failed to be practically manageable. It may be compared to the *Great Eastern* steamship, but with the difference that at the time of its construction we had but the most elementary experience of air vessels propelled by engines. At the same time this enormous capacity had its advantages. Had it been of half the diameter and half the length, though the resistance to propulsion might have been only one-quarter, the volume and the lifting power would only have been one-eighth. So that, instead of carrying engines of 32-horsepower, as was done, it might have only been possible to carry some of 4-horsepower. Dr. Pole, in his most valuable little treatises, years ago pointed out the advantages of very large volume.

One result, then, of recent experiments is that it seems quite practicable to build a navigable balloon to go, we will say, 15 miles an hour. This, however, is not quite enough. As the wind so often blows faster than this, it is unsafe to let the balloon out on any but a very calm day; else, though only blowing 16 miles an hour, the machine will inevitably be carried off and have to descend in strange fields far from its shed, and the difficulties of transporting it back may be so great that it may even have to be taken to pieces. Having successfully accomplished this much, however, it certainly looks as if we could improve a little and get the balloon to travel 20 or 25 miles an hour, which would be sufficient to stem the ordinary light breezes.

We have learned many practical lessons from these recent experiences. It is necessary to make efficient provision against the balloon caving in or buckling up. It is, of course, most important that the engine shall be so constructed as not by any possible means to be able to ignite the gas in the balloon. But especially we have learned that—speaking in general terms—for a cigar-shaped vessel some 20 feet in diameter it is necessary to apply a power of more than 16 horsepower (presuming no exceptionally efficient propeller be found) for it to be really efficient. This practically means that you must have a larger balloon.

MM. Lebaudy have now adopted a larger balloon, enabling them to carry an engine of 40 horsepower, or more than double the power of that of M. Santos Dumont. Colonel Renard, also, is about to build one larger still, of some 90,000 cubic feet. Dr. Barton's proposed air ship is also designed to be of great size.

Passing from the balloon—that is to say, any apparatus which displaces a volume of air weighing as much as or more than its own weight (and many thoughtless inventors are apt to neglect this definition)—we find several different types of machines which show promise of success.

Beginning with the simplest, we have the gliding or soaring machine. One of the greatest paradoxes in nature is soaring flight. I have said how doubtful many people might be about aerial navigation if they had never seen a bird fly, but we can confidently assert that no man would believe it possible for a bird to maintain itself for hour after hour in mid-air without the slightest movement of its wings were the actual demonstration of it not visible every day. I will not now enter on a discussion as to how this is accomplished, but will only say that there are inventors who hope to be able to emulate the albatross and soar away into the heavens without any motive power or propeller. It seems so paradoxical that many laugh the idea away. But the hard fact remains that birds can do it, and therefore why not men? I received a letter only a few days ago from Mr. O. Chanute, than whom there is probably no greater authority living on soaring flight. He says that he had just returned from witnessing this season's gliding experiments of the Brothers Wright, and that "they have made a very considerable advance since last year, and now glide at angles of 6° to 7°, sustaining 125 to 160 pounds per net horsepower. Wright is now doing nearly as well as the vulture, is not far from soaring flight, and I am changing my views as to the advisability of applying a motor."

I think this is a most remarkable statement, and there really seems no reason why such experts, having attained proficiency in the delicate art of balancing themselves according to the various puffs and currents of air, should not be able to soar away on the wings of the wind and remain indefinitely in mid-air.

The next general type of apparatus that I may refer to is that of rising in the air by means of a screw propeller mounted on a vertical shaft We all have seen little toys ascend in the air working on this principle. A large machine of this sort was recently constructed in Paris, but the experiments of Mr. W. G. Walker, of carefully testing the thrust and lifting power of various screws, have been among the most important contributions to this science. He has clearly shown that it is possible to practically obtain a thrust of 25 pounds per horsepower. As engines are now made weighing no more than 10 pounds per horsepower, it is clearly demonstrable that a machine on this principle could be constructed to lift itself, carrying some 15 pounds per horsepower over and above the weight of the engines. Even if not a practical form of machine for traveling through the air, it would be a most interesting experiment to try.

Finally we come to that variety of aerial machine which has been adopted by most inventors and which seems to promise the most satisfactory results. I mean what is known as the aeroplane. Sir Hiram Maxim brought this prominently forward many years ago, and both he and Professor Langley have proved theoretically that it is the most economical form of apparatus; that is to say, that a given weight can be supported with less engine power than by other methods.

Great progress has also been achieved in recent years in this line. Lilienthal pointed out the greater efficiency of curved surfaces as compared to flat ones. Phillips and Hargraves experimented further with aerocurves. Considering how much more we know about the subject now than when Maxim first built his machine, it looks as though we might really hear of great results shortly from America or Australia.

Our present position is, then, a hopeful one. Balloons have been gradually improved until we can practically rely on building one to go 15 miles an hour and probably more. Large flying machines, giving practical experience of their construction, have been built. Good-sized models have flown well through the air. Gliding machines, balanced and controlled by human effort, have been maintained in the air for considerable periods and have descended at very gradual angles. And, what is of the greatest importance, small engines, giving great power for their weight, have steadily improved year by year, leaving but little for us to desire in this respect.

All that we require, then, to attain practical flight, is to make a machine only slightly better than those already in existence. To accomplish this all that is required is a certain amount of skill and a good deal of money.

There has often been a lot of wild speculation about what might happen when flying machines are introduced into everyday life, but it may be worth while considering for one moment what is likely to result, so as to judge whether the matter is one really demanding an effort to accomplish; whether, in fact, "the game is worth the candle."

Whatever the exact form the apparatus may take, we may assume that it will possess certain characteristics. The first of these is that it will travel very fast. There are several reasons for supposing this. Not only must it be able to stem ordinary light breezes, but to be really useful it should be capable of going against any ordinary wind, and to do this at any useful speed implies a rate of 40 or 50 miles an hour. Then, high speeds are economical in aerial machines. Langley, by his elaborate experiments, has shown that the faster our aeroplane is propelled through the air the less force in proportion is required to sustain it. Again, the air ship, unlike its prototype on the water, is not impeded by skin friction, so that the power required to drive it at high speeds does not increase in the same proportion. A bullet can be propelled through the air at immense speed, but if it

enters the water its way is soon stopped. One more reason why we may hope for greater speeds than are usual in traveling on land and sea is that in the latter pace must be kept within bounds for fear of collision, both with other conveyances and also with irregularities (whether in rails, embankments, and ridges, or rocks and sand banks) which may exist beside the track.

In the aerial highway we have greater latitude. We have height as well as length and breadth. We can choose our particular altitude and stratum to travel in, so that perhaps 1,000 machines could cross over the same spot at the same time without colliding. In fact, it would decrease the chance of collision by a thousandfold, in addition to the lateral route not being so circumscribed. There are no police traps up there.

Taking into consideration the speed at which birds travel, that at which models have been flown, and the theoretical calculations which have been made, we may reasonably suppose that 100 miles an hour will be no excessive speed for a flying machine.

Those who think this estimate oversanguine may ponder over an extract I recently came across from an old newspaper published seventy-eight years ago, referring to the railway then about to be constructed from London to Woolwich. In this reference is made to the possibility of the train being able to attain the terrific speed of 18 to 20 miles an hour; but it concludes, with sarcastic incredulity, "We should as soon expect the people of Woolwich to be fired off on one of Congreve's rockets as to trust themselves to the mercy of such a machine going at such a rate."

Once a practical flying machine existed, the uses to which it might be applied are varied and important.

Primarily, it would form an incalculably valuable engine of war. One can scarcely imagine any invention which could have a greater effect on the conduct of warfare.

We can now appreciate much more than we could three years ago of what vast importance such a machine would be. It is worth dreaming for a moment to realise what might have happened had we in 1899 had some machine capable of traveling rapidly through the air. First of all, for mere reconnoitering, how much could have been done! In Natal, on the outbreak of war, such a vessel, ascending at Ladysmith, could have cruised around up to Laing's Nek, noting every Boer and every gun within, say, 5 miles of the track passed over, taking a turn round along the frontier, and have been back to report within a few hours. We would then, at "one fell swoop," have had certain, reliable, and full information of what was doing, instead of going on mere rumors and the vague observations of a few scouts. Another machine at Orange River could have moved forward, noted the position of the enemy at Belmont, Modder River, and

Magersfontein, could have gone into besieged Kimberley and heard their news, and could have run back to report to Lord Methuen. I need not repeat the many instances that occur to me of the extreme value of such an apparatus for reconnoissance. We might really say that none of those awkward reverses which we suffered in the early part of the war would have occurred had we known the exact whereabouts of the enemy. Latterly, how easily the evasive commanders could have been located and followed up. Reconnoissance by captive balloon may be considered dangerous, but an apparatus traveling 150 feet a second runs an infinitely smaller chance of being hit by projectiles. If the dropping of explosives on the heads of an enemy is not now considered "fair play" (though it is difficult to see why this should be less humane than throwing lyddite shells from a howitzer), yet there are many more uses to which the aerial fighter might be put.

He could blow up the railway lines and bridges, even if he had to descend to do so. He could cut all the telegraph wires in the country, and could set light to stores and do other damage. A machine soaring about over a town or camp occupied by the enemy would certainly have a very decided moral effect on him. Communication could be kept up with, and even, perhaps, a few stores introduced into a besieged place.

I need not go further into the possibilities of the future. The more we think the matter over the more can we realize the extraordinary effect such an innovation would produce in war. I do not think anyone would deny that, had we been in possession of such apparatus during the late war, the operations would have been so greatly facilitated that the campaign would have been ended in a comparatively short time, and that we should have been saved an expenditure of many millions of pounds.

Even in naval warfare, if such speeds as I have mentioned were possible, the aerial machine should prove of infinitely more value than a submarine or a torpedo boat. If the invention of the Brennan torpedo was considered worth £110,000, how much more would be the value of a dirigible aerial torpedo!

Another important purpose to which flying machines could be applied would be for the exploration of unknown lands. With a rapidly traveling apparatus, the North Pole could be reached in a few hours. From the north of Norway it is about 1,300 miles to the pole. It would then be almost possible to go there and back in twenty-four hours. When we think of the large sums which have been devoted to arctic and antarctic explorations, and remember that very possibly a tenth of this amount might produce a machine capable of thoroughly exploring both these regions in a few weeks, it seems really worth considering whether such money is not wasted. The trackless deserts

of Asia and Africa could be traversed and re-traversed, the mysteries of Mecca and of Lassa laid at our feet.

But over and above these most important and far-reaching possibilities of aerial navigation, there is the likelihood of a revolution in our ordinary modes of travel by one infinitely more rapid, cheap, and convenient. I have already given my reason for supposing that such a means of travel would be rapid. There is also good reason for supposing it would be economical. No rails or permanent way need be laid on the billows of the clouds. No roads need be constructed or kept in order through the realms of blue. Even expensive harbors, dredged channels, light-houses, and beacons need not be maintained by the owners of air ships. Going from place to place "as the crow flies" shortens the route and adds to the economy. The convenience of the system is also evident. Already we are beginning to appreciate the value of the motor car going from door to door instead of our having to get to the train at a fixed moment. But when we can order round our aerial motor to take us straight to our destination, passing equally well over land or water, towns or cornfields, independent of traffic and roads, then only shall we realize what real convenience of travel is.

Speed, economy, and convenience are big factors in a new mode of travel.

But there is one consideration which I believe is greatly responsible for the tardiness with which this subject progresses. Perils and dangers loom before us as a skeleton contaminating and haunting our castle in the air. The mere idea of being poised high up in the sky, and of falling from the machine through thousands of feet to mother earth, is so terrible to contemplate. But the aeronaut of to-day soon gets accustomed to being at a giddy height, and without doubt the people of to-morrow will have no qualms. Imagine the feelings of the savage who for the first time sees an express train rush through a station at 60 miles an hour, banging and clattering with fiendish uproar, shaking the very ground, and darting along at a speed incomparable to anything he has ever seen before. Would he trust himself to travel by that means? Though to flit through the air with the speed of a swallow may seem highly dangerous to our inexperienced minds, how often do we see a bird fall headlong to the ground?

What we see, then, looming in the future, more or less near, according to the energies of, and the encouragement we give to, those pushing the matter forward, is the introduction of a new invention forming an invaluable and all-powerful weapon of war, an important aid to science and the practical knowledge of our globe, and a speedy, economical, and pleasant mode of getting from place to place, such as will probably completely revolutionize our present methods of travel. Is this to be hastened and encouraged? If so, how can we help to

further the cause? Like most matters in this world, what is most wanted is money. Many clever inventors and engineers are quite ready with their plans, but have not the means to complete them. We see millions of pounds spent on equipment for war. Hundreds of thousands devoted to the building of small war ships. We see thousands subscribed for geographical exploration. But for the encouragement of that invention which may be paramount over all these we see practically nothing devoted. When I say "practically nothing" I am not forgetful of a certain few who have devoted much to this cause. We do not forget the very generous donations which Mr. Alexander has given to this society, nor the valuable time and energy which our worthy secretary has devoted so gratuitously to further the objects of the society. Others, too, are helping as best they can with limited time and money; but what we would like to see would be a real solid fund built up, such as would enable us to get really useful work done. Then I feel sure it would not be long before the British nation would owe a debt of gratitude to the Aeronautical Society of Great Britain.

SOME AERONAUTICAL EXPERIMENTS.[a]

Mr. Wilbur Wright, Dayton, Ohio.

[Presented to the Western Society of Engineers September 18, 1901.]

INTRODUCTION BY PRESIDENT CHANUTE.

"Engineers have, until recent years, fought shy of anything relating to aerial navigation. Those who ventured, in spite of the odium attached to that study, to look into it at all became very soon satisfied that the great obstacle in the way was the lack of a motor sufficiently light to sustain its weight and that of an aeroplane upon the air. Fifteen years ago the lightest steam motor was the marine engine, weighing 60 pounds to the horsepower, while the gas engine weighed very much more; the locomotive weighed 200 pounds per horsepower. During the past fifteen years a great change has taken place. Steam motors have been produced weighing only 10 pounds per horsepower, and gas engines have been lightened down to 12½ to 15 pounds per horsepower, so that the status, so far as engineers are concerned, is very greatly changed, and there is some hope that, for some limited purposes at least, man will eventually be able to fly through the air. There is, however, before that can be carried out—before a motor can be applied to a flying machine—an important problem to solve—that of safety or that of stability.

"I had the honor of telling you, some four or five years ago, something about the progress that had been made up to that time. Since then further advances have been made by two gentlemen from Dayton, Ohio—Mr. Wilbur Wright and Mr. Orville Wright—who tried some very interesting experiments in October, 1900. These experiments were conducted on the seashore of North Carolina, and were again resumed last July. These gentlemen have been bold enough to attempt some things which neither Lilienthal, nor Pilcher, nor myself dared to do. They have used surfaces very much greater in extent than those which hitherto had been deemed safe, and they have accomplished very remarkable results, part of which it was my privilege to see on a visit which I made to their camp about a month ago.

"I thought it would be interesting to the members of this society to be the first to learn of the results accomplished, and therefore I have the honor of presenting to you Mr. Wilbur Wright."

[a] Reprinted by permission, after revision by the author, from Journal of the Western Society of Engineers, December, 1901.

The difficulties which obstruct the pathway to success in flying-machine construction are of three general classes: (1) Those which relate to the construction of the sustaining wings; (2) those which relate to the generation and application of the power required to drive the machine through the air; (3) those relating to the balancing and steering of the machine after it is actually in flight. Of these difficulties two are already to a certain extent solved. Men already know how to construct wings or aeroplanes which, when driven through the air at sufficient speed, will not only sustain the weight of the wings themselves, but also that of the engine and of the engineer as well. Men also know how to build engines and screws of sufficient lightness and power to drive these planes at sustaining speed. As long ago as 1894 a machine weighing 8,000 pounds demonstrated its power both to lift itself from the ground and to maintain a speed of from 30 to 40 miles per hour, but failed of success owing to the inability of the operators to balance and steer it properly. This inability to balance and steer still confronts students of the flying problem, although nearly eight years have passed. When this one feature has been worked out, the age of flying machines will have arrived, for all other difficulties are of minor importance.

The person who merely watches the flight of a bird gathers the impression that the bird has nothing to think of but the flapping of its wings. As a matter of fact this is a very small part of its mental labor. To even mention all the things the bird must constantly keep in mind in order to fly securely through the air would take a considerable part of the evening. If I take this piece of paper, and after placing it parallel with the ground, quickly let it fall, it will not settle steadily down as a staid, sensible piece of paper ought to do, but it insists on contravening every recognized rule of decorum, turning over and darting hither and thither in the most erratic manner, much after the style of an untrained horse. Yet this is the style of steed that men must learn to manage before flying can become an everyday sport. The bird has learned this art of equilibrium, and learned it so thoroughly that its skill is not apparent to our sight. We only learn to appreciate it when we try to imitate it. Now, there are two ways of learning how to ride a fractious horse: One is to get on him and learn by actual practice how each motion and trick may be best met; the other is to sit on a fence and watch the beast a while, and then retire to the house and at leisure figure out the best way of overcoming his jumps and kicks. The latter system is the safest, but the former, on the whole, turns out the larger proportion of good riders. It is very much the same in learning to ride a flying machine; if you are looking for perfect safety, you will do well to sit on a fence and watch the birds; but if you really wish to learn, you must mount a machine and become acquainted with its tricks by actual trial.

Herr Otto Lilienthal seems to have been the first man who really comprehended that balancing was the first instead of the last of the great problems in connection with human flight. He began where others left off, and thus saved the many thousands of dollars that it had theretofore been customary to spend in building and fitting expensive engines to machines which were uncontrollable when tried. He built a pair of wings of a size suitable to sustain his own weight, and made use of gravity as his motor. This motor not only cost him nothing to begin with, but it required no expensive fuel while in operation, and never had to be sent to the shop for repairs. It had one serious drawback, however, in that it always insisted on fixing the conditions under which it would work. These were, that the man should first betake himself and machine to the top of a hill and fly with a downward as well as a forward motion. Unless these conditions were complied with, gravity served no better than a balky horse—it would not work at all. Althougth Lilienthal must have thought the conditions were rather hard, he nevertheless accepted them till something better should turn up; and in this manner he made some two thousand flights, in a few cases landing at a point more than 1,000 feet distant from his place of starting. Other men, no doubt, long before had thought of trying such a plan. Lilienthal not only thought, but acted; and in so doing probably made the greatest contribution to the solution of the flying problem that has ever been made by any one man. He demonstrated the feasibility of actual practice in the air, without which success is impossible. Herr Lilienthal was followed by Mr. Pilcher, a young English engineer, and by Mr. Chanute, a distinguished member of the society I now address. A few others have built gliding machines, but nearly all that is of real value is due to the experiments conducted under the direction of the three men just mentioned.

The balancing of a gliding or flying machine is very simple in theory. It consists in causing the center of gravity to coincide with the center of pressure. But in actual practice there seems to be an almost boundless incompatibility of temper which prevents their remaining peaceably together for a single instant, so that the operator, who in this case acts as peacemaker, often suffers injury to himself while attempting to bring them together. If a wind strikes a vertical plane, the pressure on that part to one side of the center will exactly balance that on the other side, and the part above the center will balance that below. But if the plane be slightly inclined, the pressure on the part nearest the wind is increased and the pressure on the other part decreased, so that the center of pressure is now located, not in the center of the surface, but a little toward the side which is in advance. If the plane be still further inclined the center of pressure will move still farther forward, and if the wind blow a little to one

side it will also move over as if to meet it. Now, since neither the wind nor the machine for even an instant maintains exactly the same direction and velocity, it is evident that the man who would trace the course of the center of pressure must be very quick of mind; and he who would attempt to move his body to that spot at every change must be very active indeed. Yet this is what Herr Lilienthal attempted to do, and did do with most remarkable skill, as his two thousand glides sufficiently attest. However, he did not escape being overturned by wind gusts several times, and finally lost his life as the result of an accidental fall. The Pilcher machine was similar to that of Lilienthal. On one occasion, while exhibiting the flight of his machine to several members of the Aëronautical Society of Great Britain, it suddenly collapsed and fell to the ground, causing injuries to the operator which proved sadly fatal. The method of managment of this machine differed in no important respect from that of Lilienthal, the operator shifting his body to make the centers of pressure and gravity coincide. Although the fatalities which befell the designers of these machines may have been due to the lack of structural strength rather than to lack of control, nevertheless it had become clear to the students of the problem that a more perfect method of control must be evolved. The Chanute machines marked a great advance in both respects. In the multiple wing machine the tips folded slightly backward under the pressure of wind gusts, so that the travel of the center of pressure was thus largely counterbalanced. The guiding of the machine was done by a slight movement of the operator's body toward the direction in which it was desired that the machine should go. The double-deck machine, built and tried at the same time, marked a very great structural advance, as it was the first in which the principles of the modern truss bridges were fully applied to flying-machine construction. This machine, in addition to its greatly improved construction and general design of parts, also differed from the machine of Lilienthal in the operation of its tail. In the Lilienthal machine the tail, instead of being fixed in one position, was prevented by a stop from folding downward beyond a certain point, but was free to fold upward without any hindrance. In the Chanute machine the tail was at first rigid, but afterwards, at the suggestion of Mr. Herring, it was held in place by a spring that allowed it to move slightly either upward or downward with reference to its normal position, thus modifying the action of the wind gusts upon it, very much to its advantage. The guiding of the machine was effected by slight movements of the operator's body, as in the multiple-wing machines. Both these machines were much more manageable than the Lilienthal type, and their structural strength, notwithstanding their extreme lightness, was such that no fatalities or even accidents marked the glides made with them, although winds

were successfully encountered much greater in violence than any which previous experimenters had dared to attempt.

My own active interest in aeronautical problems dates back to the death of Lilienthal in 1896. The brief notice of his death which appeared in the telegraphic news at that time aroused a passive interest which had existed from my childhood and led me to take down from the shelves of our home library a book on Animal Mechanism, by Professor Marey, which I had already read several times. From this I was led to read more modern works, and as my brother soon became equally interested with myself we soon passed from the reading to the thinking, and finally to the working stage. It seemed to us that the main reason why the problem had remained so long unsolved was that no one had been able to obtain any adequate practice. We figured that Lilienthal in five years of time had spent only about five hours in actual gliding through the air. The wonder was not that he had done so little, but that he had accomplished so much. It would not be considered at all safe for a bicycle rider to attempt to ride through a crowded city street after only five hours' practice, spread out in bits of ten seconds each over a period of five years; yet Lilienthal with this brief practice was remarkably successful in meeting the fluctuations and eddies of wind gusts. We thought that if some method could be found by which it would be possible to practice by the hour instead of by the second there would be hope of advancing the solution of a very difficult problem. It seemed feasible to do this by building a machine which would be sustained at a speed of 18 miles per hour, and then finding a locality where winds of this velocity were common. With these conditions, a rope attached to the machine to keep it from floating backward would answer very nearly the same purpose as a propeller driven by a motor, and it would be possible to practice by the hour, and without any serious danger, as it would not be necessary to rise far from the ground, and the machine would not have any forward motion at all. We found, according to the accepted tables of air pressures on curved surfaces that a machine spreading 200 square feet of wing surface would be sufficient for our purpose, and that places could easily be found along the Atlantic coast where winds of 16 to 25 miles were not at all uncommon. When the winds were low it was our plan to glide from the tops of sand hills, and when they were sufficiently strong to use a rope for our motor and fly over one spot. Our next work was to draw up the plans for a suitable machine. After much study we finally concluded that tails were a source of trouble rather than of assistance; and therefore we decided to dispense with them altogether. It seemed reasonable that if the body of the operator could be placed in a horizontal position instead of the upright, as in the machines of Lilienthal, Pilcher, and Chanute, the wind resistance could be very materially reduced, since only 1 square foot

instead of 5 would be exposed. As a full half horsepower could be saved by this change, we arranged to try at least the horizontal position. Then the method of control used by Lilienthal, which consisted in shifting the body, did not seem quite as quick or effective as the case required; so, after long study, we contrived a system consisting of two large surfaces on the Chanute double-deck plan, and a smaller surface placed a short distance in front of the main surfaces in such a position that the action of the wind upon it would counterbalance the effect of the travel of the center pressure on the main surfaces. Thus changes in the direction and velocity of the wind would have little disturbing effect, and the operator would be required to attend only to the steering of the machine, which was to be affected by curving the forward surface up or down. The lateral equilibrium and the steering to right or left was to be attained by a peculiar torsion of the main surfaces, which was equivalent to presenting one end of the wings at a greater angle than the other. In the main frame a few changes were also made in the details of construction and trussing employed by Mr. Chanute. The most important of these were (1) the moving of the forward main crosspiece of the frame to the extreme front edge; (2) the encasing in the cloth of all crosspieces and ribs of the surfaces; (3) a rearrangement of the wires used in trussing the two surfaces together, which rendered it possible to tighten all the wires by simply shortening two of them.

With these plans we proceeded in the summer of 1900 to Kitty Hawk, N. C., a little settlement located on the strip of land that separates Albemarle Sound from the Atlantic Ocean. Owing to the impossibility of obtaining suitable material for a 200 square foot machine, we were compelled to make it only 165 square feet in area, which according to the Lilienthal tables would be supported at an angle of 3° in a wind of about 21 miles per hour. On the very day that the machine was completed the wind blew from 25 to 30 miles per hour, and we took it out for trial as a kite. We found that, while it was supported with a man on it in a wind of about 25 miles, its angle was much nearer 20° than 3°. Even in gusts of 30 miles the angle of incidence did not get as low as 3°, although the wind at this speed has more than twice the lifting power of a 21-mile wind. As winds of 30 miles per hour are not plentiful on clear days, it was at once evident that our plan of practicing by the hour, day after day, would have to be postponed. Our system of twisting the surfaces to regulate the lateral balance was tried and found to be much more effective than shifting the operator's body. On subsequent days, when the wind was too light to support the machine with a man on it, we tested it as a kite, working the rudders by cords reaching to the ground. The results were very satisfactory; yet we were well aware that this method of testing is never wholly convincing until the results are confirmed by actual gliding experience.



FIG. 1.—THE 1900 MACHINE.



FIG. 2.—KITE SOARING.



FIG. 1.—A BOTTOM VIEW.



FIG. 2.—STARTING A FLIGHT.

We then turned our attention to making a series of actual measurements of the lift and drift of the machine under various loads. So far as we were aware this had never previously been done with any full-size machine. The results obtained were most astonishing, for it appeared that the total horizontal pull of the machine, while sustaining a weight of 52 pounds, was only 8.5 pounds, which was less than had previously been estimated for head resistance of the framing alone. Making allowance for the weight carried, it appeared that the head resistance of the framing was but little more than 50 per cent of the amount which Mr. Chanute had estimated as the head resistance of the framing of his machine. On the other hand, it appeared sadly deficient in lifting power as compared with the calculated lift of curved surfaces of its size. This deficiency we supposed might be due to one or more of the following causes: (1) That the depth of the curvature of our surfaces was insufficient, being only about 1 in 22 instead of 1 in 12. (2) That the cloth used in our wings was not sufficiently air tight. (3) That the Lilienthal tables might themselves be somewhat in error. We decided to arrange our machine for the following year so that the depth of curvature of its surfaces could be varied at will and its covering air-proofed.

Our attention was next turned to gliding, but no hill suitable for the purpose could be found near our camp at Kitty Hawk. This compelled us to take the machine to a point 4 miles south, where the Kill Devil sand hill rises from the flat sand to a height of more than 100 feet. Its main slope is toward the northeast and has an inclination of about 10°. On the day of our arrival the wind blew about 25 miles an hour, and as we had had no experience at all in gliding we deemed it unsafe to attempt to leave the ground. But on the day following, the wind having subsided to 14 miles per hour, we made about a dozen glides. It had been the original intention that the operator should run with the machine to obtain initial velocity and assume the horizontal position only after the machine was in free flight. When it came time to land he was to resume the upright position and light on his feet, after the style of previous gliding experimenters. But on actual trial we found it much better to employ the help of two assistants in starting, which the peculiar form of our machine enabled us readily to do, and in landing we found that it was entirely practicable to land while still reclining in a horizontal position upon the machine. Although the landings were made while moving at speeds of more than 20 miles an hour, neither machine nor operator suffered any injury. The slope of the hill was 9.5°, or a drop of 1 foot in 6. We found that after attaining a speed of about 25 or 30 miles with reference to the wind, or 10 to 15 miles over the ground, the machine not only glided parallel to the slope of the hill, but greatly increased its speed, thus indicating its ability to glide on a somewhat less angle than 9.5°, when we should feel it safe to rise higher from the surface. The control of the machine proved even better than we had dared to expect,

responding quickly to the slightest motion of the rudder. With these glides our experiments for the year 1900 closed. Although the hours and hours of practice we had hoped to obtain finally dwindled down to about two minutes, we were very much pleased with the general results of the trip, for, setting out as we did, with almost revolutionary theories on many points and an entirely untried form of machine, we considered it quite a point to be able to return without having our pet theories completely knocked in the head by the hard logic of experience, and our own brains dashed out in the bargain. Everything seemed to us to confirm the correctness of our original opinions, (1) that practice is the key to the secret of flying; (2) that it is practicable to assume the horizontal position; (3) that a smaller surface set at a negative angle in front of the main bearing surfaces, or wings, will largely counteract the effect of the fore and aft travel of the center of pressure; (4) that steering up and down can be attained with a rudder without moving the position of the operator's body; (5) that twisting the wings so as to present their ends to the wind at different angles is a more prompt and efficient way of maintaining lateral equilibrium than shifting the body of the operator.

When the time came to design our new machine for 1901, we decided to make it exactly like the previous machine in theory and method of operation. But as the former machine was not able to support the weight of the operator when flown as a kite, except in very high winds and at very large angles of incidence, we decided to increase its lifting power. Accordingly, the curvature of the surfaces was increased to 1 in 12, to conform to the shape on which Lilienthal's table was based, and to be on the safe side we decided also to increase the area of the machine from 165 square feet to 308 square feet, although so large a machine had never before been deemed controllable. The Lilienthal machine had an area of 151 square feet, that of Pilcher 165 square feet, and the Chanute double-decker 134 square feet. As our system of control consisted in a manipulation of the surfaces themselves instead of a shifting of the operator's body, we hoped that the new machine would be controllable, notwithstanding its great size. According to calculations, it would obtain support in a wind of 17 miles per hour with an angle of incidence of only 3°.

Our experience of the previous year having shown the necessity of a suitable building for housing the machine, we erected a cheap frame building, 16 feet wide, 25 feet long, and 7 feet high at the eaves. As our machine was 22 feet wide, 14 feet long (including the rudder), and about 6 feet high, it was not necessary to take the machine apart in any way in order to house it. Both ends of the building, except the gable parts, were made into doors, which hinged above, so that when opened they formed an awning at each end and left an entrance the full width of the building. We went into camp about the middle of July, and were soon joined by Mr. E. C. Huffaker,

of Tennessee, an experienced aeronautical investigator in the employ of Mr. Chanute, by whom his services were kindly loaned, and by Dr. G. A. Spratt, of Pennsylvania, a young man who has made some valuable investigations of the properties of variously curved surfaces and the travel of the center of pressure thereon. Early in August Mr. Chanute came down from Chicago to witness our experiments and spent a week in camp with us. These gentlemen, with my brother and myself, formed our camping party, but in addition we had in many of our experiments the valuable assistance of Mr. W. J. Tate and Mr. Dan. Tate, of Kittyhawk.

The machine was completed and tried for the first time on the 27th of July, in a wind blowing about 13 miles an hour. The operator having taken a position where the center of pressure was supposed to be, an attempt at gliding was made, but the machine turned downward and landed after going only a few yards. This indicated that the center of gravity was too far in front of the center of pressure. In the second attempt the operator took a position several inches farther back, but the result was much the same. He kept moving farther and farther back with each trial, till finally he occupied a position nearly a foot back of that at which we had expected to find the center of pressure. The machine then sailed off and made an undulating flight of a little more than 300 feet. To the onlookers this flight seemed very successful, but to the operator it was known that the full power of the rudder had been required to keep the machine from either running into the ground or rising so high as to lose all headway. In the 1900 machine one-fourth as much rudder action had been sufficient to give much better control. It was apparent that something was radically wrong, though we were for some time unable to locate the trouble. In one glide the machine rose higher and higher till it lost all headway. This was the position from which Lilienthal had always found difficulty to extricate himself, as his machine then, in spite of his greatest exertions, manifested a tendency to dive downward almost vertically and strike the ground head on with frightful velocity. In this case a warning cry from the ground caused the operator to turn the rudder to its full extent and also to move his body slightly forward. The machine then settled slowly to the ground, maintaining its horizontal position almost perfectly, and landed without any injury at all. This was very encouraging, as it showed that one of the very greatest dangers in machines with horizontal tails had been overcome by the use of a front rudder. Several glides later the same experience was repeated with the same result. In the latter case the machine had even commenced to move backward, but was nevertheless brought safely to the ground in a horizontal position. On the whole, this day's experiments were encouraging, for while the action of the rudder did not seem at all like that of our 1900 machine, yet we had escaped without difficulty from positions which had proved very dangerous to preceding experiment-

ers, and after less than one minute's actual practice had made a glide of more than 300 feet, at an angle of descent of 10°, and with a machine nearly twice as large as had previously been considered safe. The trouble with its control, which has been mentioned, we believed could be corrected when we should have located its cause. Several possible explanations occurred to us, but we finally concluded that the trouble was due to a reversal of the direction of the travel of the center pressure at small angles. In deeply curved surfaces the center of pressure at 90° is near the center of the surface, but moves forward as the angle becomes less, till a certain point is reached, varying with the depth of curvature. After this point is passed, the center of pressure, instead of continuing to move forward, with the decreasing angle, turns and moves rapidly toward the rear. The phenomena are due to the fact that at small angles the wind strikes the forward part of the surface on the upper side instead of the lower, and thus this part altogether ceases to lift, instead of being the most effective part of all, as in the case of the plane. Lilienthal had called attention to the danger of using surfaces with a curvature as great as 1 in 8, on account of this action on the upper side; but he seems never to have investigated the curvature and angle at which the phenomena entirely cease. My brother and I had never made any original investigation of the matter, but assumed that a curvature of one in twelve would be safe, as this was the curvature on which Lilienthal based his tables. However, to be on the safe side, instead of using the arc of a circle, we had made the curve of our machine very abrupt at the front, so as to expose the least possible area to this downward pressure. While the machine was building Messrs. Huffaker and Spratt had suggested that we would find this reversal of the center of pressure, but we believed it sufficiently guarded against. Accordingly, we were not at first disposed to believe that this reversal actually existed in our machine, although it offered a perfect explanation of the action we had noticed in gliding. Our peculiar plan of control by forward surfaces, instead of tails, was based on the assumption that the center of pressure would continue to move farther and farther forward as the angle of incidence became less, and it will be readily perceived that it would make quite a difference if the front surface instead of counteracting this assumed forward travel should in reality be expediting an actual backward movement. For several days we were in a state of indecision, but were finally convinced by observing the following phenomena (fig. 1): We had removed the upper surface from the machine and were flying it in a wind to see at what angles it would be supported in winds of different strengths. We noticed that in light winds it flew in the upper position shown in the figure, with a strong upward pull on the cord *c*. As the wind became stronger the angle of incidence became less, and the surface flew in the position shown in the middle of the figure, with a slight



FIG. 1.—A HIGH GLIDE.



FIG. 2.—A LOW GLIDE.

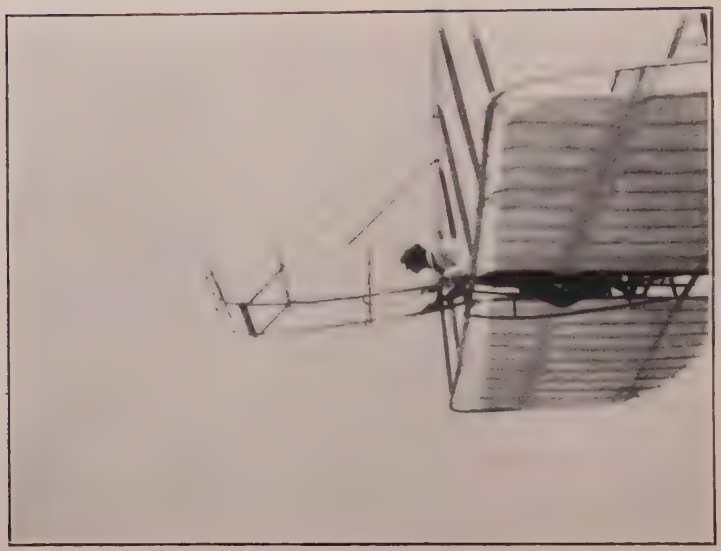


FIG. 1.—SOARING.

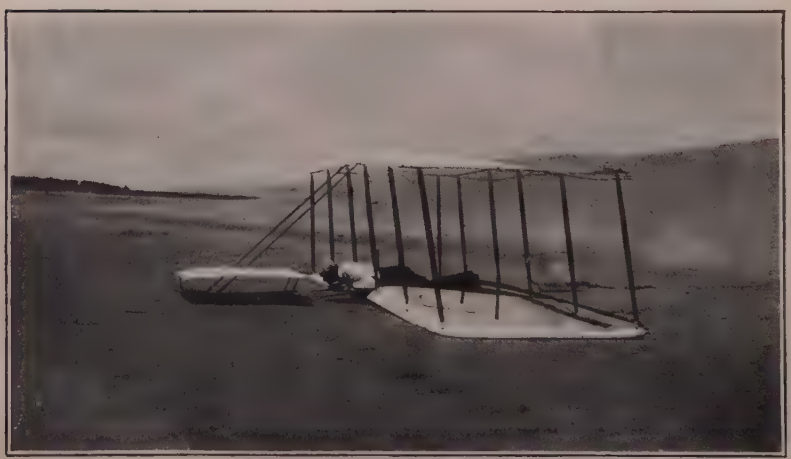


FIG. 2.—LANDING.

horizontal pull; but when the wind became still stronger it took the lower position shown in the figure, with a strong downward pull. It at once occurred to me that here was the answer to our problem, for it is evident that in the first case the center of pressure was in front of the center of gravity, and thus pushed up the front edge; in the second case they were in coincidence and the surface in equilibrium, while in the third case the center of pressure had reached a point even behind the center of gravity, and there was therefore a downward pull on the

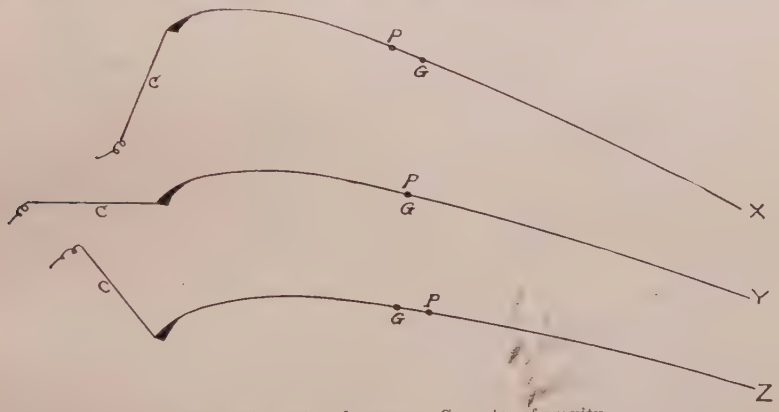


FIG. 1.—*P*, center of pressure; ~~*G*, center~~ of gravity.

cord. This point having been definitely settled, we proceeded to truss down the ribs of the whole machine, so as to reduce the depth of curvature. In fig. 2 line 1 shows the original curvature; line 2, the curvature when supporting the operator's weight, and line 3, the curvature after trussing.

On resuming our gliding, we found that the old conditions of the preceding year had returned, and after a few trials made a glide of 366 feet and soon after one of 389 feet. The machine with its new

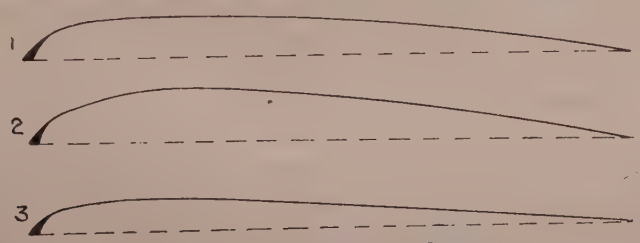


FIG. 2.—Diagrams of pressures and curves.

curvature never failed to respond promptly to even small movements of the rudder. The operator could cause it to almost skim the ground, following the undulations of its surface, or he could cause it to sail out almost on a level with the starting point, and passing high above the foot of the hill, gradually settle down to the ground. The wind on this day was blowing 11 to 14 miles per hour. The next day, the conditions being favorable, the machine was again taken out for trial.

This time the velocity of the wind was 18 to 22 miles per hour. At first we felt some doubt as to the safety of attempting free flight in so strong a wind, with a machine of over 300 square feet, and a practice of less than five minutes spent in actual flight. But after several preliminary experiments we decided to try a glide. The control of the machine seemed so good that we then felt no apprehension in sailing boldly forth. And thereafter we made glide after glide, sometimes following the ground closely and sometimes sailing high in the air. Mr. Chanute had his camera with him and took pictures of some of these glides, several of which are among those shown.

We made glides on subsequent days, whenever the conditions were favorable. The highest wind thus experimented in was a little over 12 meters per second—nearly 27 miles per hour.

It had been our intention when building the machine to do the larger part of the experimenting in the following manner: When the wind blew 17 miles an hour or more we would attach a rope to the machine and let it rise as a kite with the operator upon it. When it should reach a proper height the operator would cast off the rope and glide down to the ground just as from the top of a hill. In this way we would be saved the trouble of carrying the machine up hill after each glide, and could make at least ten glides in the time required for one in the other way. But when we came to try it we found that a wind of 17 miles, as measured by Richard's anemometer, instead of sustaining the machine with its operator, a total weight of 240 pounds, at an angle of incidence of 3°, in reality would not sustain the machine alone—100 pounds—at this angle. Its lifting capacity seemed scarcely one-third of the calculated amount. In order to make sure that this was not due to the porosity of the cloth, we constructed two small experimental surfaces of equal size, one of which was air-proofed and the other left in its natural state; but we could detect no difference in their lifting powers. For a time we were led to suspect that the lift of curved surfaces little exceeded that of planes of the same size, but further investigation and experiment led to the opinion that (1) the anemometer used by us overrecorded the true velocity of the wind by nearly 15 per cent; (2) that the well-known Smeaton coefficient of $0.005\ V^2$ for the wind pressure at 90° is probably too great by at least 20 per cent; (3) that Lilienthal's estimate that the pressure on a curved surface having an angle of incidence of 3° equals 0.545 of the pressure at 90° is too large, being nearly 50 per cent greater than very recent experiments of our own with a special pressure-testing machine indicate; (4) that the superposition of the surfaces somewhat reduced the lift per square foot, as compared with a single surface of equal area.

In gliding experiments, however, the amount of lift is of less relative importance than the ratio of lift to drift, as this alone decides the angle of gliding descent. In a plane the pressure is always per-

pendicular to the surface, and the ratio of lift to drift is therefore the same as that of the cosine to the sine of the angle of incidence. But in curved surfaces a very remarkable situation is found. The pressure, instead of being uniformly normal to the chord of the arc, is usually inclined considerably in front of the perpendicular. The result is that the lift is greater and the drift less than if the pressure were normal. Lilienthal was the first to discover this exceedingly important fact, which is fully set forth in his book, Bird Flight the Basis of the Flying Art, but owing to some errors in the methods he used in making measurements, question was raised by other investigators not only as to the accuracy of his figures, but even as to the existence of any tangential force at all. Our experiments confirm the existence of this force, though our measurements differ considerably from those of Lilienthal. While at Kitty Hawk we spent much time in measuring the horizontal pressure on our unloaded machine at various angles of incidence. We found that at 13° the horizontal pressure was about 23 pounds. This included not only the drift proper, or horizontal component of the pressure on the side of the surface, but also the head resistence of the framing as well. The weight of the machine at the time of this test was about 108 pounds. Now, if the pressure had been normal to the chord of the surface, the drift proper would have been to the lift (108 pounds) as the sine of 13° is to the cosine of 13°, or $\frac{.22 \times 108}{.97} = 24+$ pounds; but this slightly exceeds the total pull of 23 pounds on our scales. Therefore it is evident that the average pressure on the surface instead of being normal to the chord was so far inclined toward the front that all the head resistance of framing and wires used in the construction was more than overcome. In a wind of 14 miles per hour resistance is by no means a negligible factor, so that tangential is evidently a force of considerable value. In a higher wind, which sustained the machine at an angle of 10°, the pull on the scales was 18 pounds. With the pressure normal to the chord the drift proper would have been $\frac{.17 \times 98^a}{.98} = 17$ pounds, so that, although the higher wind velocity must have caused an increase in the head resistance, the tangential force still came within 1 pound of overcoming it. After our return from Kitty Hawk we began a series of experiments to accurately determine the amount and direction of the pressure produced on curved surfaces when acted upon by winds at the various angles from zero to 90°. These experiments are not yet concluded, but in general they support Lilienthal in the claim

[a] The travel of the center of pressure made it necessary to put sand on the front rudder to bring the centers of gravity and pressure into coincidence. Consequently the weight of the machine varied from 98 pounds to 108 pounds in the different tests.

that the curves give pressures more favorable in amount and direction than planes; but we find marked differences in the exact values, especially at angles below 10°. We were unable to obtain direct measurements of the horizontal pressures of the machine with the operator on board, but by comparing the distance traveled in gliding with the vertical fall it was easily calculated that at a speed of 24 miles per hour the total horizontal resistances of our machine when bearing the operator amounted to 40 pounds, which is equivalent to about 2⅔ horsepower. It must not be supposed, however, that a motor developing this power would be sufficient to drive a man-bearing machine. The extra weight of the motor would require either a larger machine, higher speed, or a greater angle of incidence in order to support it, and therefore more power. It is probable, however, that an engine of 6 horsepower, weighing 100 pounds, would answer the purpose. Such an engine is entirely practicable. Indeed, working motors of one-half this weight per horsepower (9 pounds per horsepower) have been constructed by several different builders. Increasing the speed of our machine from 24 to 33 miles per hour reduced the total horizontal pressure from 40 to about 35 pounds. This was quite an advantage in gliding as it made it possible to sail about 15 per cent farther with a given drop. However, it would be of little or no advantage in reducing the size of the motor in a power-driven machine, because the lessened thrust would be counterbalanced by the increased speed per minute. Some years ago Professor Langley called attention to the great economy which might be obtained by using very high speeds, and from this many were led to suppose that speeds of 50 or 60 miles an hour were essential to success; but the introduction of curved surfaces as substitutes for planes has very greatly reduced the speed of greatest economy. The probability is that the first flying machines will have a relatively low speed, perhaps not much exceeding 20 miles per hour, but the problem of increasing the speed will be much simpler in some respects than that of increasing the speed of a steamboat; for, whereas in the latter case the size of the engine must increase as the cube of the speed, in the flying machine until extremely high speeds are reached the capacity of the motor increases in less than simple ratio; and there is even a decrease in the fuel consumption per mile of travel. In other words, to double the speed of a steamship (and the same is true of the balloon type of air ship) eight times the engine and boiler capacity would be required and four times the fuel consumption per mile of travel; while a flying machine would require engines of less than double the size, and there would be an actual decrease in the fuel consumption per mile of travel. But, looking at the matter conversely, the great disadvantage of the flying machine is apparent; for in the latter no flight at all is possible unless the proportion of horsepower to flying capacity is very high; but, on the other hand, a steamship is

a mechanical success if its ratio of horsepower to tonnage is insignificant. A flying machine that would fly at a speed of 50 miles an hour with engines of 1,000 horsepower would not be upheld by its wings at all at a speed of less than 25 miles an hour, and nothing less than 500 horsepower could drive it at this speed. But a boat which could make 40 miles per hour with engines of 1,000 horsepower would still move 4 miles an hour even if the engines were reduced to 1 horsepower. The problems of land and water travel were solved in the nineteenth century, because it was possible to begin with small achievements and gradually work up to our present success. The flying problem was left over to the twentieth century, because in this case the art must be highly developed before any flight of considerable duration can be obtained.

However, there is another way of flying which requires no artificial motor, and many workers believe that success will first come by this road. I refer to the soaring flight, by which the machine is permanently sustained in the air by the same means that are employed by soaring birds. They spread their wings to the wind, and sail by the hour, with no perceptible exertion beyond that required to balance and steer themselves. What sustains them is not definitely known, though it is almost certain that it is a rising current of air. But whether it be a rising current or something else, it is as well able to support a flying machine as a bird, if man once learns the art of utilizing it. In gliding experiments it has long been known that the rate of vertical descent is very much retarded and the duration of the flight greatly prolonged if a strong wind blows up the face of the hill parallel to its surface. Our machine, when gliding in still air, has a rate of vertical descent of nearly 6 feet per second, while in a wind blowing 26 miles per hour up a steep hill we made glides in which the rate of descent was less than 2 feet per second. And during the larger part of this time, while the machine remained exactly in the rising current, there was no descent at all, but even a slight rise. If the operator had had sufficient skill to keep himself from passing beyond the rising current, he would have been sustained indefinitely at a higher point than that from which he started. The illustration shows one of these very slow glides at a time when the machine was practically at a standstill. The failure to advance more rapidly caused the photographer some trouble in aiming, as you will perceive. In looking at this picture you will readily understand that the excitement of gliding experiments does not entirely cease with the breaking up of camp. In the photographic dark room at home we pass moments of as thrilling interest as any in the field, when the image begins to appear on the plate and it is yet an open question whether we have a picture of a flying machine or merely a patch of open sky. These slow glides in rising currents probably hold out greater hope of extensive practice than any other method within man's reach, but they have

the disadvantage of requiring rather strong winds or very large supporting surfaces. However, when gliding operators have attained greater skill, they can, with comparative safety, maintain themselves in the air for hours at a time in this way, and thus by constant practice so increase their knowledge and skill that they can rise into the higher air and search out the currents which enable the soaring birds to transport themselves to any desired point by first rising in a circle to a great height and then sailing off at a descending angle. The last illustration shows the machine, alone, flying in a wind of 35 miles per hour on the face of a steep hill 100 feet high. It will be seen that the machine not only pulls upward, but also pulls forward in the direction from which the wind blows, thus overcoming both gravity and the speed of the wind. We tried the same experiment with a man on it, but found danger that the forward pull would become so strong that the men holding the ropes would be dragged from their insecure foothold on the slope of the hill. So this form of experimenting was discontinued after four or five minutes' trial.

In looking over our experiments of the past two years, with models and full-size machines, the following points stand out with clearness:

1. That the lifting power of a large machine, held stationary in a wind at a small distance from the earth, is much less than the Lilienthal table and our own laboratory experiments would lead us to expect. When the machine is moved through the air, as in gliding, the discrepancy seems much less marked.

2. That the ratio of drift to lift in well-shaped surfaces is less at angles of incidence of 5° to 12° than at an angle of 3°.

3. That in arched surfaces the center of pressure at 90° is near the center of the surface, but moves slowly forward as the angle becomes less, till a critical angle, varying with the shape and depth of the curve, is reached, after which it moves rapidly toward the rear till the angle of no lift is found.

4. That with similar conditions large surfaces may be controlled with not much greater difficulty than small ones, if the control is effected by manipulation of the surfaces themselves, rather than by a movement of the body of the operator.

5. That the head resistances of the framing can be brought to a point much below that usually estimated as necessary.

6. That tails, both vertical and horizontal, may with safety be eliminated in gliding and other flying experiments.

7. That a horizontal position of the operator's body may be assumed without excessive danger, and thus the head resistance reduced to about one-fifth that of the upright position.

8. That a pair of superposed or tandem surfaces has less lift in proportion to drift than either surface separately, even after making allowance for weight and head resistance of the connections.

STELLAR EVOLUTION IN THE LIGHT OF RECENT RESEARCH.[a]

By Prof. GEORGE E. HALE,
Director of the Yerkes Observatory, University of Chicago.

Many attempts have been made to sum up the work of the nineteenth century and to define its principal lines of progress. In estimates of the relative importance of the books published during this period there has been some divergence of view, but regarding one of them no element of doubt seems to have entered the minds of the critics. By unanimous consent Darwin's Origin of Species is accorded a commanding position among the works which have influenced the intellectual life of the century. It would be difficult to overestimate the effect which the doctrine of evolution has wrought. The principle of orderly and harmonious development which it embodies has found application, not only in explaining the wide diversity of organic species, but in unifying the events of history, in elucidating the origin of language, and in throwing light on difficult questions in every department of human knowledge. The idea of evolution may indeed be traced back through the writings of many centuries. The early philosophers, though not possessed of the immense collection of recorded phenomena by which modern men of science may test their theories, were constantly occupied with great problems demanding the widest generalization. In attempting to account for the earth and its inhabitants they made the first steps in the direction which Darwin subsequently pursued.

It would be interesting to recall the strange traditions in which primitive peoples have recorded their vague imaginings of the origin of things. But the absence of even an attempt at careful reasoning renders such tales of no value for our present purpose. The Greek philosophers were not oblivious to the value of observation as a check on speculation regarding the solar system, but the instruments then

[a] Revised from an address delivered on June 5, 1901, before the Minnesota Chapter of the Honorary Scientific Society of Sigma XI, University of Minnesota. Reprinted by permission of the author, after revision, from Popular Science Monthly, February, 1902.

available were too crude to give accurate positions of the heavenly bodies. Even Copernicus, though he established the sun at the center of our system, and thus paved the way for the nebular hypothesis, retained the epicycles of the Greeks. Kepler, basing his investigations upon the observations of Tycho Brahe, proved that the planets move in ellipses with the sun at the focus, and removed all vestige of doubt as to the general plan of the solar system. The harmony which characterizes the motions of the planets and a knowledge of the effect of gravitation led Kant to formulate an explanation of the origin of the solar system, which subsequently found more perfect expression in the nebular hypothesis of Laplace.

In this hypothesis Laplace seeks to account for the formation of the sun and planets through the contraction of a vast nebulous cloud which once filled the entire solar system, extending to the orbit of Neptune. This mass, which he considered to be fiery hot, was supposed to be in rotation. As it cooled, through radiation into space, it contracted toward the center. The result of this contraction was to increase the velocity of rotation, and when through increasing velocity the centrifugal force at the periphery counterbalanced the attraction of the central mass a ring was thrown off. Further contraction resulted in the formation of other rings, in each of which the matter collected about its densest part, and thus produced a planet. Before they had time to cool these planets in turn threw off rings, which, with the single exception of Saturn's ring system, condensed into satellites.

This celebrated hypothesis, though unsupported by mathematical proof, has occupied a dominant position since the time of its publication, more than a century ago. It has been subjected to much criticism, but most of the objections raised by Faye and others have been met by modifications of the hypothesis. Of late it has encountered fresh attacks on the part of Chamberlin and Moulton; and it now seems doubtful whether it will be possible to overcome their criticisms, which are based on dynamical considerations. It may prove to be sufficient, however, to forsake the lenticular mass of vapor predicated by Laplace in favor of the spiral form which Keeler has shown to characterize so many nebulæ.

The nebular hypothesis seeks to account for a system like our own, wherein a central sun is surrounded by planets and satellites, originally self-luminous, but ultimately cooled to the point where they are luminous only through reflected light. The stars are so distant from us that any planets which may attend them are beyond the reach of the most powerful telescopes. In some of the planetary and spiral nebulæ, such as the Great Nebula in Andromeda (Pl. I), we perhaps observe the earlier stages of the process of condensation, but no distinct evidence of progressive change has yet been gathered from telescopic



GREAT NEBULA IN ANDROMEDA.

Photographed with the 2-foot reflecting telescope of the Yerkes Observatory (Ritchey).



STAR TRAILS PHOTOGRAPHED WITH 2½-INCH POTRAIT LENS (RITCHEY).

observation. In seeking for evidence of stellar evolution, on a plan comprehensive enough to include a place for every star in the heavens, we may begin with visual and photographic observations with the telescope. Such remarkable photographs as that of the Andromeda nebula seem to bring us into the very presence of a greater system, perhaps more nearly comparable in size with the Milky Way than with the solar system, in the actual process of formation. But on account of the long periods of time which must elapse before changes in this distant mass may become sufficiently great to be appreciable, and for many other reasons, we could not hope to base a complete scheme of stellar evolution on such photographs alone. Our observational methods must also include the means of solving physical, chemical, and gravitational problems as they present themselves, not close at hand in the laboratory, but in inconceivably distant regions of space. For this reason it would have been impossible prior to the invention of the spectroscope to arrange the stars according to any clearly defined system of development. The principal advances which have been made in the study of stellar evolution are therefore confined to the period which has elapsed since the middle of the nineteenth century.

Thus the investigation of stellar evolution has been contemporaneous with the investigation of organic evolution. Indeed, the epoch-making discovery of the chemical composition of the sun by Kirchhoff and Bunsen was made in the year of the publication of the Origin of Species. Before this discovery the meaning of spectral lines had been as obscure as the meaning of Egyptian hieroglyphs prior to the discovery of the Rosetta stone. After it the chemical analysis of a star became hardly less difficult than the analysis of an unknown substance in the laboratory. Furthermore, it soon became apparent that the light of a star, as decomposed by a prism, was competent to define the star's position in a general scheme of development, in which every advance from the unformed nebulous cloud on through the highest degree of stellar brilliancy to such a final stage as is typified by the moon can be defined with but little danger of error. Before we proceed to consider some of the evidences of stellar evolution, let us examine some of the instruments and methods without which the discoveries to be subsequently described would have been impossible.

I shall confine my remarks on modern astrophysical instruments to those at present employed at the Yerkes Observatory, partly because nearly all the celestial photographs reproduced in the figures were taken with these instruments and partly because of the convenience of illustrating them. But before describing the great telescope which forms the principal apparatus of the observatory, I wish to point out that many of the most important results of astronomy, results which could not be obtained with a powerful telescope for the very reason of its great power, have been derived from the use of an ordinary camera

with just such a lens as is found in the possession of thousands of amateur photographers. If we take an ordinary camera and point it on a clear night toward the North Pole, it will be found after an exposure of one or two hours that the stars which lie near the pole have drawn arcs of circles upon the plate (Pl. II). This is due to the fact that the earth is rotating upon its axis at such a rate as to cause every star in the sky to appear to travel through a complete circle once in twenty-four hours The nearer the star to the pole the smaller does this circle become. As we move away from the pole we find the curvature of the star trails growing less and less, until at the equator they appear as straight lines.

Just such photographs as these are frequently employed in astronomical investigations; e. g., for the purpose of recording variations in a star's brightness, which would be shown on the plate by changes in the brightness of the trail. But for most purposes it is desirable to have photographs of stars in which they are represented as points of light rather than as lines. To obtain such photographs it is necessary to mount the camera in such a way that it can be turned about an axis parallel to the earth's axis once in twenty-four hours. A camera so mounted becomes an equatorial photographic telescope, differing in no important respect save in the construction of its lens from an instrument like the 40-inch Yerkes telescope.

But the scale of the photographs obtained with such a camera differs in marked degree from that of the photographs furnished by the telescope. Here, for example, is a region of the Milky Way, photographed by Professor Barnard with one of the old-fashioned lenses formerly employed in portrait galleries (Pl. III). Such a picture as this is of the greatest service in all studies of the structure of the Milky Way, for it brings before us at a single glance an immense region of the sky, thus permitting us to trace the general features which are common to this area. You will notice in the midst of this star cloud a little cluster of stars, here so densely packed together that no details of the cluster can be distinguished. If our investigations required us to single out some individual star in the cluster, perhaps for the purpose of analyzing its light, it is evident that the portrait lens would prove inadequate for our purpose. It is in such a case as this that an instrument like the 40-inch telescope comes into play. The camera with which this photograph was taken has a lens 6 inches in diameter, of 31 inches focal length. The great telescope has a lens 40 inches in diameter, of 64 feet focal length. Thus the scale of the photographs made with the telescope is about twenty-five times that of the photographs made with the portrait lens. The portrait lens covers a large area of the sky on a very small scale, while the field of the telescope is limited to a small region, which is depicted on a large scale. Let us see the difference between the two instruments as illustrated by



STAR CLUSTER MESSIER 11 AND THE SURROUNDING MILKY WAY.

Small scale photograph taken with potrait lens (Barnard). The cluster, here about one-sixteenth of an inch in diameter, lies just above the middle of the picture.



STAR CLUSTER MESSIER 11.

Large scale photograph taken with the 40-inch Yerkes telescope (Ritchey).

the photographs themselves (compare Pl. III with Pl. IV). The small cluster, which in reality contains several thousands of stars, is resolved by Mr. Ritchey's photograph, taken with the large telescope, into all its constituent parts, stars less than one second of arc apart being clearly separated on this great scale.

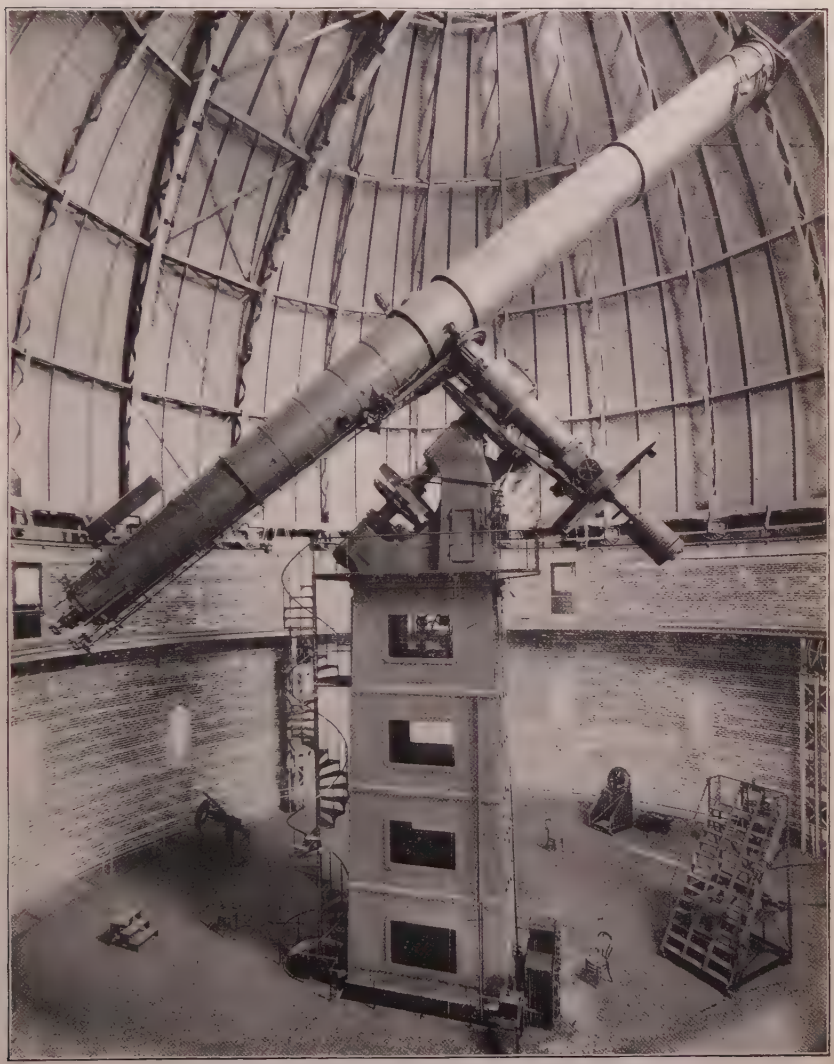
Having seen this illustration of the superior power of the large telescope you may perhaps be interested to become more closely acquainted with the instrument itself (Pl. V). The great weight of the 40-inch lens, amounting with its cell to half a ton, requires that the tube which supports it, here taking the place of the camera box of the previous instrument, shall be of immense rigidity and strength. This tube, 64 feet in length, is supported at its middle point by the declination axis, which in its turn is carried by the polar axis, adjusted to accurate parallelism with the axis of the earth. By means of driving mechanism in the upper section of the iron column the whole instrument is turned about this polar axis at such a rate that it would complete one revolution in twenty-four hours. Although the moving parts weigh over 20 tons, the telescope can be directed to any part of the sky by hand, but this operation is much facilitated by the use of electric motors provided for the purpose. When once directed toward the object to be observed it will frequently happen that the lower end of the telescope is far out of reach above the observer's head. For this reason the entire floor of the observing room, 75 feet in diameter, is constructed like an electric elevator, which, by throwing a switch, can be made to rise or fall through a distance of 23 feet. Thus the lower end of the telescope is rendered accessible even for objects near the horizon. In order that the observing slit may be directed to any part of the sky the dome, 90 feet in diameter, is mounted on wheels and can be turned to any desired position by means of an electric motor controlled from the rising-floor.

The telescope is used for a great variety of purposes in conjunction with appropriate instruments, which are attached to the lower end of the tube near the point where the image is formed. I have already shown a photograph of a star cluster taken with this telescope, but without describing the process of making it. As a matter of fact the object-glass of the 40-inch telescope was designed for visual observations, and its maker, the late Alvan G. Clark, had no idea that it would ever be employed for photography. Without dwelling upon the distinguishing features of visual and photographic lenses I may say that the former is so designed by the optician as to unite into an image those rays of light, particularly the yellow and the green, to which the eye is most sensitive. With the only varieties of optical glass which can be obtained in large pieces it is impossible to unite in a single clearly defined image all of the red, the yellow, the green, the blue, and the violet rays which reach us from a star. Therefore when the

optician decides to produce an image most suitable for eye observations he deliberately discards the blue and violet rays, simply because they are less important to the eye than the yellow and green rays. For this reason the image of a star produced by a large refracting telescope is surrounded by a blue halo containing the rays discarded by the optician. These very rays, however, are the ones to which the ordinary photographic plate is most sensitive; hence in a photographic telescope the blue and violet rays are united, while the yellow and green rays are discarded.

The 40-inch telescope is of the first type, constructed primarily for visual observations. In order to adapt it for photography Mr. G. W. Ritchey, of the observatory staff, simply places before the (isochromatic) plate a thin screen of yellow glass, which cuts out the blue rays, but allows the yellow and green rays to pass. As isochromatic plates are sensitive to yellow and green light, there is no difficulty in securing an image with the rays which the object glass unites into a perfect image. During the entire time of the exposure a star which lies just outside the region to be photographed is observed through an eyepiece magnifying 1,000 diameters. This eyepiece is attached to the frame which carries the photographic plate, and is susceptible of motion in two directions at right angles to each other. In the center of the eyepiece are two very fine cross hairs of spider web illuminated by a small incandescent lamp. If the observer notices that through some slight irregularity in the motion of the telescope, or through some change of refraction in the earth's atmosphere, the star image is moving away from the point of intersection of the cross hairs, he instantly brings it back by means of one or both of the screws. As the plate moves with the eyepiece it is evident that this method furnishes a means of keeping the star images exactly at the same point on the plate throughout the entire exposure. With such apparatus certain data are gathered for the study of stellar development.

It is easier to trace the successive steps in the development of a star after it has been formed than it is to account for its origin, but all the evidence that has been accumulated up to the present time tends to show that stars are condensed out of the cloud-like masses which we know as nebulæ. Less than half a century has passed since the true nature of a gaseous nebula was determined. In his extensive observations of astronomical phenomena Sir William Herschel examined a great number of star clusters similar to that shown in Plate IV. His telescope was a large one, but it can safely be said that he never saw a cluster so well as this object can be perceived through the aid of photography. He found in studying object after object in all parts of the heavens that many clusters could be resolved into their constituent stars. In some of these clusters the stars are widely separated by a powerful instrument, as they appear in this photograph. In others,



THE 40-INCH TELESCOPE OF THE YERKES OBSERVATORY.



CENTRAL PARTS OF THE GREAT NEBULA IN ORION.
Photographed with the 40-inch Yerkes telescope (Ritchey).

either on account of their greater distance or because the stars are less widely spaced, the central regions are no longer clearly resolvable as separate objects. It is thus quite possible to imagine a cluster in which the stars are so closely grouped that no telescope, however powerful, could distinguish them separately.

Now, as a matter of fact, we find in all parts of the heavens luminous objects which can not be separated into stars. Some of these are of definite outline and are perfectly symmetrical in form, in many cases with a brilliant star-like nucleus at their center. These are known as the planetary nebulæ. Other nebulæ, like the great nebula in Orion (Pl. VI), are diffuse and irregular and extend over great regions of the sky. It was long a question whether such objects were capable of resolution into stars with a sufficiently powerful telescope. Herschel rightly concluded that an important distinction can be drawn between a nebula and a star cluster, though his son did not admit this distinction.

It was only after Huggins had applied the spectroscope to an analysis of the light of a nebula that it could be said without danger of contradiction that the phenomenon is not one produced by the crowding together of separate stars, but is due to the presence of a mass of incandescent gas. Sir William Huggins's account of his first spectroscopic examination of a nebula is recorded in the first volume of the Publications of the Tulse Hill Observatory:

"On the evening of August 29, 1864, I directed the spectroscope for the first time to a planetary nebula in Draco. I looked into the spectroscope. No spectrum such as I had expected! A single bright line only! At first I suspected some displacement of the prism and that I was looking at a reflection of the illuminated slit from one of its faces. This thought was scarcely more than momentary; then the true interpretation flashed upon me. The light of the nebula was monochromatic, and so, unlike any other light I had as yet subjected to prismatic examination, could not be extended out to form a complete spectrum. After passing through the two prisms it remained concentrated into a single bright line, having a width corresponding to the width of the slit, and occupying in the instrument a position at that part of the spectrum to which its light belongs in refrangibility. A little closer looking showed two other bright lines on the side toward the blue, all three lines being separated by intervals relatively dark. The riddle of the nebulæ was solved. The answer, which had come to us in the light itself, read: Not an aggregation of stars, but a luminous gas."

With this advance a new era of progress began. The power of the spectroscope to distinguish between a glowing gas and a mass of partially condensed vapors like a star established it at once in its place as the chief instrument of the student of stellar evolution. It became apparent that the unformed nebula might furnish the stuff from which stars are made. Observations tending to this conclusion were not long

in presenting themselves. In the heart of the Orion nebula are four small stars which constitute the well-known Trapezium. Situated as they are in the midst of this far-reaching mass of gas, it is not hard to picture them as centers of condensation, toward which the play of gravitational forces tends to concentrate the gases of the nebula. It might therefore be expected that stars in this early stage of growth should show through the spectroscopic analysis of their light some evidence of relationship with the surrounding nebula. Now, this is precisely what the spectroscope has demonstrated. Not only these stars, but many other stars in the constellation of Orion are shown by the spectroscope to contain the same gases which constitute the nebula. For this and other reasons they are considered to represent one of the earliest stages of stellar growth.

It may be many years before the exact nature of the process by which a star is formed from a nebulous mass is clearly understood. Shortly before his death the late Professor Keeler made a most important discovery in the course of his photographic work with the Crossley reflector of the Lick Observatory. Spiral nebulæ have long been known, but it was not supposed that they were sufficiently numerous to be regarded as type objects. The great spiral nebula illustrated by one of Mr. Ritchey's recent reflector photographs (Pl. VII) has long been regarded as one of the most remarkable objects in the heavens, and the possible significance of its form had by no means been overlooked. But few astronomers were prepared for Professor Keeler's announcement that the majority of nebulæ are of the spiral form and that many thousands of these objects are within the reach of such an instrument as the Crossley reflector. It does not seem improbable that this spiral form may prove to represent the original condensing mass more truly than the lenticular form from which Laplace imagined the solar system to be evolved.

Enough has already been said to indicate how large a part the methods of spectroscopy must play in the study of the life history of stars. In spite of the common opinion that the spectroscope is an intricate instrument and that the principles of spectroscopy are obscure and difficult of comprehension, it is a fact that the processes used in this field of investigation can be easily understood by anyone who will devote a very small amount of time to the subject. As you doubtless know, the essential feature of a star spectroscope is the prism or train of prisms by which the star light is divided into its constituent parts. After passing through the prisms the light of the star is spread out into a long band, which shows all the colors of the rainbow, beginning with red at one end and passing through orange, yellow, green, and blue to violet at the other. This band is crossed by lines, and the problem of the spectroscopist is to interpret the meaning of these lines.



SPIRAL NEBULA IN CANES VENATICI.

Photographed with the 2-foot reflecting telescope of the Yerkes Observatory (Ritchey).

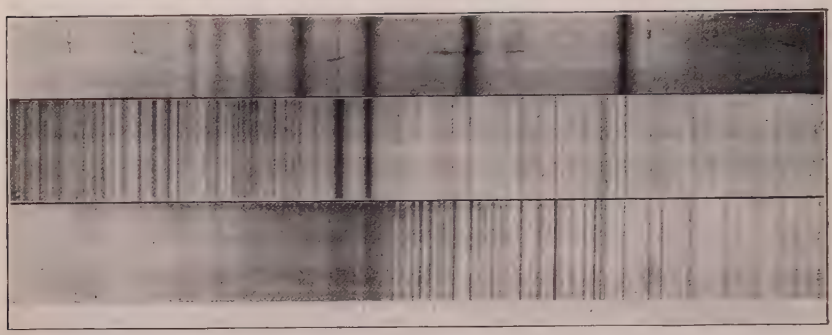


FIG. 1.—CHARACTERISTIC SPECTRA OF (*a*) WHITE, (*b*) YELLOW, AND (*c*) RED STARS (HUGGINS).



FIG. 2.—THE SOLAR CORONA.

Photographed by Yerkes Observatory Eclipse Expedition, May 28, 1900 (Barnard and Ritchey).

If the lines are dark he knows that the light of the star after originating in an interior incandescent body has passed through a mass of cooler vapors, and that during its transmission some of the light has suffered absorption. If, on the other hand, the lines are bright, he knows that the region where they are produced is hotter than that lying below. Thus a single glance at the spectrum of a star is sufficient to give important information regarding the physical condition of its atmosphere.

But the spectral lines are able to tell a far more complete story of stellar conditions. If their exact position in the spectrum can be measured it becomes possible to determine the chemical composition of the star's atmosphere. And here the spectroscopist may be said to have the advantage of the archeologist, in that the key to stellar hieroglyphs is a master key, capable of interpreting not merely the language of a single people or a single age, but of laying bare the secrets of the most distant portions of the universe and applying with equal force to the primitive and to the most highly developed forms of celestial phenomena. If we take a piece of iron wire and turn it into vapor in the intense heat of an electric arc lamp we find that the light which the glowing iron vapor emits, when spread out into a spectrum by a prism, consists of a series of lines characteristically spaced and always occupying the same relative positions. In the same way every other element when transformed into vapor by a sufficiently intense heat emits characteristic radiations, consisting of groups of lines occupying definite positions in the spectrum. It is thus easy to see how the presence of iron vapor can be detected in the atmosphere of Sirius or in that of the sun. In the spectrum of each of these stars we find a group of lines occupying the same relative positions as the lines furnished by the iron vapor in an electric arc. Hydrogen gives an even more characteristic group of lines, which grow closer and closer together as we pass from the red end of the spectrum toward the violet. This group occurs in the spectra of thousands of stars and serves as an important guide in determining a star's place in a general scheme of stellar evolution.

The practical means of carrying out this method of research may be illustrated by a reference to the stellar spectroscope employed with the 40-inch Yerkes telescope. The spectroscope is rigidly attached to the lower end of the telescope tube. The image of a star formed by the 40-inch lens passes into the spectroscope through a slit about one one-thousandth of an inch wide. After analysis by a train of three prisms an image of the resulting spectrum is formed by a suitable lens upon a photographic plate. In making the photograph it is only necessary to keep the image of a star exactly on the slit throughout the exposure, which may occupy from one minute to several hours, the duration depending upon the brightness of the star.

We have seen that a single glance at the spectrum of a star is sufficient to give us important information as to the structure of its atmosphere, while a study of the position of the lines tells what chemical elements are present. We might go on to consider how the width and sharpness of the lines, together with shifts in their position toward the red end of the spectrum, furnish the means of estimating the density of the vapors and the pressure to which they are subjected. The relative intensities of certain lines also serve as a clew to the temperature. Thus in the spectrum of magnesium there is a pair of lines, one of which is the stronger at the temperature of the electric spark, while the other is the stronger at the lower temperature of the electric arc. In the spectra of certain stars the greater intensity of the first line may indicate that the temperature is high and approximates that of the electric spark, while in other stars the relative intensities are reversed, suggesting that the temperature is lower and corresponds more closely with that of the electric arc. In addition to all this, certain easily measureable changes in the position of the spectral lines are known from Doppler's principle to indicate motion of the star in the direction of the earth. Thus, if the lines are shifted toward the red with reference to their normal position, and if we have evidence that the shift is not due to pressure, we may conclude that the distance between the earth and the star is increasing, while if the lines are shifted toward the violet we conclude that the distance between the earth and the star is decreasing. As the earth's motion is known, the velocity of the star in the line of sight can therefore be accurately determined.

After this glance at the methods employed by the spectroscopist, we may return to a further consideration of the stages of stellar evolution. We have seen that the long-continued action of gravity tends to produce condensation of a cosmical cloud. The constellation of Orion contains many examples of stars in this early stage of development. As the mass condenses its temperature rises, and corresponding with this rise in temperature and in the density of the vapors which constitute the star we find characteristic changes in the spectrum and also in the star's color. Such a brilliant white or bluish-white star as Sirius or Vega may be taken as representative of the next stage of stellar development. Here the broad bands of hydrogen, which constitute a beautiful series expressible by a simple mathematical formula, serve as the chief mark of distinction. The conditions are not yet ripe for the marked development of metallic lines, though doubtless the numerous elements which constitute the sun, and which for the most part are familiar to us on the earth, are present in such stars, though they are not revealed through a study of the spectrum. It is true that evidence exists of the presence of iron and a few other substances, but the lines are thin and few in number, and might be overlooked in a casual examination of the spectrum. The period for their greatest development has not yet arrived. The light gas hydrogen, reaching

far above the white-hot mass of condensed vapors which constitute the nucleus of the star, is at this stage the predominant element, at least so far as we may judge from a study of the light radiation.

An interesting question has arisen regarding the period in a star's life at which the highest temperature is attained. The apparently paradoxical statement of Lane's law that the temperature of a cooling mass of incandescent vapors, instead of falling, actually increases until a certain stage has passed, applies in the present instance. We, indeed, know that a condensing nebula, losing heat by radiation into space, will continue to rise in temperature for thousands and even millions of years. A question which has received some discussion of late is with regard to the precise period at which the maximum temperature occurs. Shall we seek it in white stars like Sirius or in yellow stars like the sun, which represents the next well-defined stage of stellar evolution? With an instrument of extraordinary delicacy Professor Nichols has recently measured at the Yerkes Observatory the amount of heat which we receive from Vega and Arcturus. The distance of these stars is so inconceivably great that the quantity of heat which they send to the surface of the earth has hitherto been too small to be detected by the most sensitive instruments. Professor Nichols's radiometer, which, in combination with a large concave mirror, renders it easy to measure the heat radiated from a man's face 2,000 feet away, proved adequate for the task. He found that Arcturus sends us about as much heat as we should get from a candle 6 miles away if there were no intervening atmosphere to reduce the candle's intensity. Vega, which to the eye is precisely equal to Arcturus in brightness, was found to send us only half as much heat. If the absorbing atmospheres of Arcturus and Vega were similar in character, it would follow, from Professor Nichols's results, that Vega, though it sends us less heat, is really the hotter of the two stars. For we know from laboratory experiments that the proportion of long (heat) waves to short (light) waves is greater in the radiation of the cooler of two bodies heated to incandescence. In this case the fact that Arcturus sends the greater amount of heat would be ascribed rather to greater size than to lesser distance, as there is good reason to believe that it is farther from us than Vega.

But unfortunately the dissimilarity of the atmospheres of the two stars renders it uncertain whether such conclusions can safely be drawn. This is particularly true in view of the fact that Sir William Huggins concludes from his spectroscopic studies that the highest stage of stellar temperature is reached in stars like Arcturus and the sun, while stars like Vega are still in an earlier and less highly heated condition.

While some uncertainty must therefore prevail until further investigations have been completed regarding the exact stage at which the highest stellar temperatures are attained, there can be little doubt as

to the path which is followed when through the long continued action of gravitation a young star like Vega develops into a star like the sun. We are fortunate in possessing examples of a great number of intermediate stages in this orderly progress (Pl. VIII, fig. 1). As condensation continues, and as the vapors which constitute the star continue to crowd upon each other, the stellar nucleus becomes denser and denser and the vast atmosphere of hydrogen gradually gives place to a much shallower atmosphere, in which hydrogen is still conspicuous, though it no longer predominates in a very striking manner over the other elements. The spectral lines of such elements as iron, magnesium, sodium, and calcium, rise into prominence as the hydrogen lines fade. Meanwhile the light of the star undergoes a change of color, completely losing its bluish cast and assuming a distinctly yellow hue. There can be little if any doubt that the development of our own sun must cause it to pass through some such stages as are represented by the spectra shown in Pl. VIII, fig. 1. The time which has elapsed since it acquired its present size and density as the result of the condensation of the great nebula in which the earth and the other planets also had their origin, covers many millions of years. It is fortunate for the study of stellar evolution that the stages through which the sun once passed are all exemplified in existing stars, which for unknown reasons began their stellar life at widely different times.

It will be profitable to consider for a moment some of the remarkable phenomena which are presented to us by the sun, not only because of their intrinsic interest, but also because it is perfectly safe to assume that similar phenomena, sometimes on a much greater scale, would be presented by other stars, were they not at so great a distance from the earth as to reduce them to mere points of light, even in the most powerful telescope. The sun has a diameter of 860,000 miles and, as its distance from the earth is only 93,000,000 miles, an extremely small fraction of the distance of the other stars, it is possible to observe and to study in detail its extraordinary phenomena, which are incomparably more violent than anything observed on the earth. When we speak of the sun we speak collectively of a great number of phenomena, some of which extend for millions of miles from the sun's visible disk. Chief of these is the corona, a vast filmy atmosphere so rare that it offers little or no resistance to the passage of a comet, as it sweeps around the sun under the action of gravitation and returns into the space from which it came. The polar streamers of the corona (Pl. VIII, fig. 2) suggests the action of magnetic forces and offer material for long continued study of this, the most mysterious of all the solar appendages. At the base of the corona, rising out of a sea of flame which completely encircles the sun, are the prominences, some of which occasionally attain a height of nearly 400,000 miles. Like the corona, the prominences are hidden by the brilliant illumination of our own atmosphere,

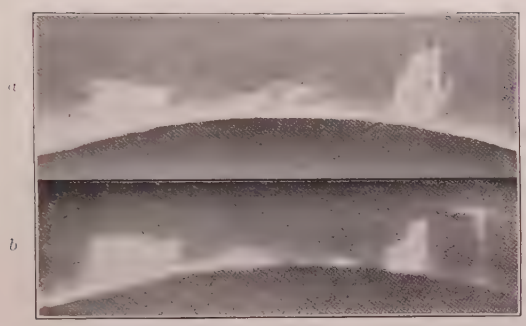
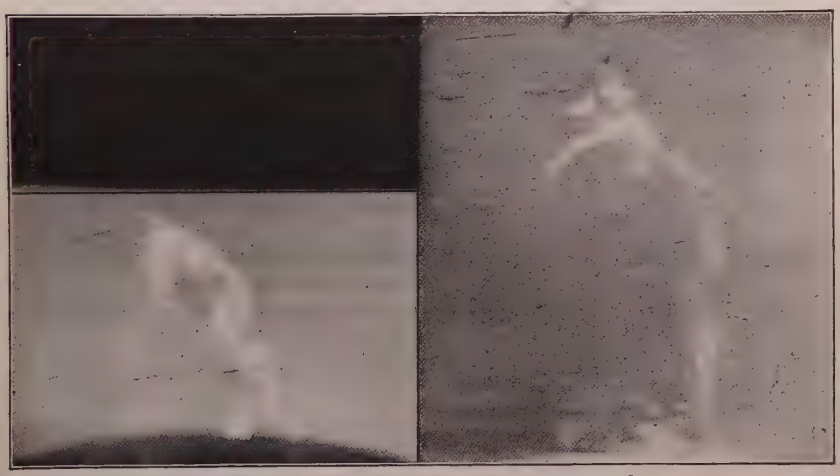


FIG. 1.—CLOUD-LIKE PROMINENCES PHOTOGRAPHED AT THE ECLIPSE OF MAY 28, 1900.

a, By Yerkes Observatory party at Wadesboro, N. C.; *b*, by Astronomer Royal, of England, at Ovar, Portugal, two hours later. The bright cross on the right of this picture is due to a defect in the original photograph.



a *b*

FIG. 2.—ERUPTIVE PROMINENCE PHOTOGRAPHED IN FULL SUNLIGHT AT THE KENWOOD OBSERVATORY, CHICAGO, MARCH 25, 1895.

a, At 10 h. 40 m. (height, 162,000 miles); *b*, at 10 h. 58 m. (height, 281,000 miles). Figs. 1 and 2 are reproduced on the same scale.



SPECTRA OF FOUR RED STARS (HALE AND ELLERMAN), SHOWING HOW THE DARK BAND, DUE TO CARBON, INCREASES IN INTENSITY AS THE STAR COOLS.

and are visible to the naked eye only when the direct light of the sun's disk is cut off by the interposition of the moon at a total eclipse. But methods have been devised by which they can be observed or photographed on any clear day through the agency of a modified form of spectroscope. The prominences are constantly changing in form, sometimes slowly, as in the case of this group (Pl. IX, fig. 1), a photograph of which, taken at the eclipse of May 28, 1900, by the astronomer royal of England in Spain, is shown for comparison with the photograph taken about two hours earlier by the Yerkes Observatory party in North Carolina. Here the change in the form of the mass of gas which constitutes the prominence is comparatively small, but that violent forces are sometimes at work may be illustrated by photographs of an eruptive prominence taken at the Kenwood Observatory in 1895 (Pl. IX, fig. 2). At the moment when the first photograph was made the prominence had attained a height of 160,000 miles and was rising rapidly. Eighteen minutes later another picture was taken; during the interval the prominence had been going upward at the rate of 6,000 miles a minute, and when the exposure was made it had reached an elevation of 280,000 miles. When looked for a few minutes later it had completely disappeared.

The constitution of the chromosphere, the sea of flame some 10,000 miles deep from which the prominences rise, increases in complexity as the surface of the solar disk is approached. In its upper part only the vapor of calcium and the light gases, hydrogen and helium, are found. But in proceeding downward the vapors of magnesium, sodium, iron, chromium, and last of all, carbon, are successively encountered. At this part of the solar atmosphere the dark lines of the solar spectrum take their rise through the effect of absorption.

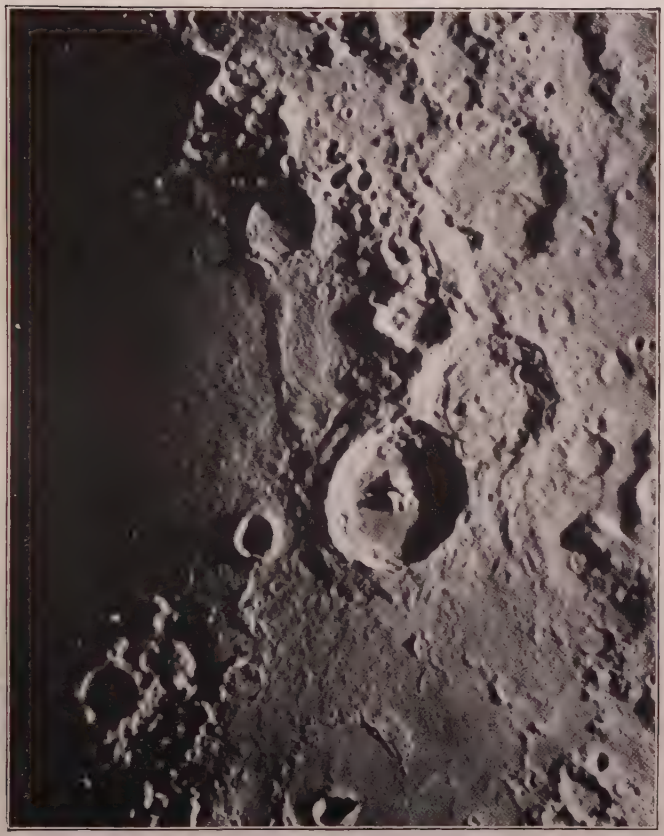
Time does not permit a detailed description of the phenomena of the sun's disk. When photographed with an instrument which excludes from the sensitive plate all light except that which is characteristic of the vapor of calcium, its surface is found to be dotted over with extensive luminous regions. Associated with these are the sun spots, the minute study of which has revealed some strikingly beautiful phenomena, which have been most successfully drawn by Langley. The surface of the sun in the regions devoid of spots is shown by the photographs of Janssen to consist of brilliant granules separated by darker spaces. Much might be said of the peculiar law of rotation of the sun, which causes a point near the equator to complete an axial rotation in much less time than a point nearer the poles. Much might also be said of the periodicity of sun spots, which at times are very numerous and again, as at present, are absent from the sun's disk for weeks together. But enough has already been told to indicate some of the chief characteristics of this central star of the solar system,

which has thousands of counterparts among other stars of the same spectral class.

We are now approaching the last chapters in the life history of a star. After the solar stage has passed the color changes from yellow to orange, and subsequently to red, as the temperature falls. The spectral lines of hydrogen become fainter and fainter and finally disappear completely. The lines of the metallic elements, on the contrary, become more and more complex and the changes in their relative intensities are those which are characteristic of lower temperatures. But curiously enough, there are two well-defined classes of these older stars, which until recently were not known to have any points in common except their red color. These are the stars of Secchi's third and fourth types. In general appearance their spectra are wholly unlike, particularly on account of the absence from third-class spectra of the broad dark bands due to the absorption of carbon vapor, the most characteristic feature of the fourth type. But in spite of this apparent dissimilarity, photographs recently taken with the 40-inch Yerkes telescope show that in certain regions of the spectrum stars of the two types are practically identical and are thus probably more closely related than formerly appeared to be the case. The measurements and reductions of a long series of photographs of fourth-type spectra now in progress at the Yerkes Observatory should soon permit us to form an opinion of the nature of these interesting stars.

In both the third and fourth types it is easy to trace the successive stages of development. In stars of the fourth type the signs of increasing age are particularly striking. The carbon vapor which produces the broad dark bands becomes denser and denser, until it is not difficult to imagine that through the further increase of such absorption the light of the star might be almost completely extinguished (Pl. X).

The phenomena of the red stars indicate that this final stage is close at hand, and curiously enough, in further testimony of the remarkable power of the spectroscope, the total extinction of a star's light does not always prove sufficient to place that star beyond the reach of this instrument. It is true that the spectroscope can not reveal the chemical composition of a solid body which is devoid of intrinsic light, but such a body may form a system with another object which is still luminous, and its gravitational power may cause the luminous body to move in an orbit. As we have already seen, the spectroscope is capable of revealing the motions of such a body. From a knowledge of these motions and the time in which the revolution is effected it is possible to determine the mass and dimensions of the system, and in some special cases, like that of Algol, the diameter and density of the invisible component of the pair.



LUNAR CRATER THEOPHILUS AND SURROUNDING REGION.

Photographed with the 40-inch Yerkes telescope (Ritchey).

A NEW SOLAR THEORY.[a]

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It is a remarkable fact that in the numerous theories which have been propounded in explanation of the periodic changes of the solar phenomena no account has yet been taken of so important an element as the light and heat absorbing envelope surrounding the photosphere. The attention which this so-called solar atmosphere has hitherto received, on the part even of our most eminent investigators, in connection with the economy of radiant energy on our luminary, is utterly disproportionate to the importance of the subject. In spite of the fact, which was first accurately established by Langley's observations and was afterwards confirmed by others, that the sun, if deprived suddenly of this protecting screen would radiate into space as much as double its present amount of energy, solar physicists failed to perceive that changes in the absorptive power of this envelope must entail consequences of the most far-reaching character with respect to the thermal conditions on and in the sun. That such changes—and these, too, of no inconsiderable magnitude—must inevitably occur, is a conclusion which it is hardly possible to evade when it is remembered that the supreme control over the dispensation of solar energy depends entirely on a thin, shallow surface layer, the matter of which is constantly tossed about by vehement eruptions and acted upon by a most complicated and powerful system of convection currents to and from the sun's center.

The possibility of variations of the opacity of the solar atmosphere was, it is true, strongly urged, more than twenty years ago, by one of the greatest authorities on this question. Shortly after his well-known researches into the absorbing faculty of the solar envelope, Langley pointed out the decisive influence on the sun's radiation into space caused by changes in the transmissive power of its atmosphere.

[a] Reprinted, with additions by the author, from Nature, No. 1685, vol. 65, February 13, 1902.

[b] Abstract of a paper in Astr. Nachr. (No. 3723, 3724): "Ueber eine neue Theorie zur Erklärung der Periodicität der solaren Erscheinungen."

But his attention was at the time solely directed toward their probable effects on the temperature of our own planet. He found that an increase of absorption by as much as 25 per cent would diminish the mean surface temperature of our globe by 100° F., while a like diminution in the solar envelope would produce a corresponding change in the opposite direction.

Now, if the influence of a change in the absorptive power of the solar atmosphere is so enormous on a planet at a distance of almost a hundred million of miles, of what inconceivable importance must it not be for the sun itself? Drawing the very natural inference that a deficit of outside radiation means a surplus of energies working upon the solar matter, and vice versa, we are forcibly led to conclude that even slight changes of opacity, such as would elude our most refined observations, are bound to greatly influence the state of thermal equilibrium on our luminary.

Hence, if changes in the absorptive power of the sun's atmosphere exist, as can not but be the case, the question presents itself: What happens with those energies which, by a condensation of the solar envelope, are prevented from escaping into space? No doubt they are preserved to the sun, but in what form? Do they raise the temperature of the solar mass, or augment its store of potential energy, or have they a share in the generation of those marvelous dynamical displays which we perceive in periodic succession on the solar surface? Questions such as these must tend to convince the investigator that a research into the causes of the variability of the forces which we see acting on the sun, if not identical with, is at least closely akin to, the investigation of the origin and the physical properties of the sun's atmosphere. I shall endeavor in these columns to demonstrate the possibility of such changes in the density of the solar envelope as would lead to alterations of the thermal conditions of the sun's mass, and shall make an attempt to answer the question as to how far these changes must be conducive to variations in the dynamical phenomena at the sun's surface.

There is perfect unanimity among astronomers as regards the nature of the force which, by a continuous generation of heat, compensates for the loss of energy into space. Helmholtz's theory, which attributes this heat generation to the progressive contraction of the solar mass as a consequence of gravitation, may be regarded as one of the most probable hypotheses ever propounded in the history of physical science. But this theory does not yet enable us to form an idea of the evolution of a celestial body. It explains the existence of a heat-generating force within the star's bulk, but it gives no answer to the question as to whether the loss of energy by radiation is exactly compensated for by the generation of energy through contraction, or whether the conditions of contraction peculiar to the sun may not

perhaps produce more or less heat than is required for compensation. It is, indeed, inconceivable that the conditions of contraction can remain the same throughout the lifetime of a star. The spectroscope has revealed the fact that the photospheres of different stars exhibit widely different stages as regards temperature. There are doubtless suns hotter than ours, and others considerably cooler. And we may confidently assume that the various conditions of temperature now recognized in the different types of star-spectra represent the phases which successively appear in the evolution of each of these bodies from its origin as a far-extended nebula down to its complete obscuration. In the life of each of these stars there will be a period when its temperature is on the ascent, and when, consequently, the heat-generating effect of the contractile force exceeds the loss by outward radiation, as well as another period when the declining temperature of the star indicates an excess of the heat-dissipating over the heat-producing forces. Which of these conditions, at the present moment, prevails on our sun can so far be only a matter of conjecture. In this respect, therefore, an assumption has to be made. The following inquiry applies to the case of a star on which the generation of energy by contraction falls short of the loss of energy by radiation. Whether the results of this investigation may be applied to the case of our sun must, then, depend on the further question whether the sun really belongs to those stars the temperature of which is declining. So far as I know, this latter opinion is at present held by the great majority of astrophysicists.

If on a star the loss of energy exceeds the production, the kinetic energy of its molecules, and consequently its absolute temperature, must decrease. Hence if the temperature of a layer, a_n, at a certain distance, ρ_n, from the center was T_1 at the epoch t_1, it will be T_2 at a later epoch t_2, where $T_2 < T_1$. Now let a_1 be the level of the photosphere—or the level of maximum incandescence, and therefore also of maximum radiation—at the epoch t_1. In consequence of deficient contraction the temperature of this layer must decrease, and the materials composing it must cool down, so that, at the subsequent epoch t_2, the level of maximum incandescence will have shifted toward a layer a_2, nearer to the star's center, where the temperature is still sufficiently high to maintain the incandescent state of all the particles. The space between a_1 and a_2 will then be occupied by particles in a less luminous state which act as an absorbing screen on the radiation emanating from a_2. Whatever fraction of the total radiation which originally left the photosphere at a_2 is thus stopped in its outward progress will be in part absorbed by, and in part reflected from, the intervening particles of the layer a_1a_2, and there can be no doubt that some at least of this arrested energy will ultimately be thrown back to a_2 from which it started. The layer a_1a_2 must therefore act on the

photospheric radiation in the same way as do our atmosphere and its clouds on the radiation from the soil. We are quite familiar with the fact that clear nights are, as a rule, cooler than cloudy ones, and we explain this phenomenon by the assumption that on clear nights radiation from the soil into space goes on more freely than when clouds offer an effective impediment to the dissipation of radiant energy.

We conclude, then, that the progressive cooling of the star leads to the formation of an absorbing envelope above its photosphere, by which the disproportion between the generation and loss of energy is reduced. But if, under the conditions at the epoch t_2, the amount of energy actually radiated into space still exceeds what is produced by contraction, the photosphere will move to a_3, still nearer to the centre, and the quantity of absorbing matter in the layer $a_1 a_3$ will be further increased. Now, although a_3 emits the same quantity of energy as did a_2 and a_1 at the former epochs, the total amount of radiation emerging into space must, at the epoch t_3, be less than it was at t_2 and t_1. Thus the opacity of the cooled atmosphere gradually increases as time goes on, and the total radiation of the star becomes less and less. Since no force is present to interfere with the cooling of the layers $a_1, a_2 \ldots$, a moment t_n must eventually be reached at which the photosphere at a_n, through reflection from all the layers above it, receives back so much of its radiation that its total expenditure of energy is exactly counterbalanced by the energy contributed by the contractile forces.

This result appears to be of eminent importance, for it shows that even on a star with deficient contraction the exact compensation of the loss of energy may still be possible from a certain layer downward. This state, so exceedingly important for the conservation of energy within the star, is brought about by the progressive cooling of its superficial layers, which thereby increase their power of absorption, and thus offer a more and more effective check to the radiation from the incandescent layers below.

Here, now, we are confronted with a question which leads us at once to the principal object of this inquiry: Can the state of thermal equilibrium thus eventually attained by the layer a_n be permanent? The answer is clearly negative. For when a_n has arrived at this state, none of the layers $a_1, a_2 \ldots a_{n-1}$ outside a_n have reached the same condition. Their cooling is bound to go on, and consequently their ability to absorb and reflect the heat emanating from the layer a_n must still further increase even after the establishment of thermal equilibrium at a_n. But, owing to this increasing amount of reflection toward it, the layer a_n will now dissipate even less energy than is required for the maintenance of thermal equilibrium, and therefore must become overheated. It thus comes to pass that, while the function of the absorbing envelope is that of reducing as much as possible the waste of energy from the photospheric layers, it is, by the very

nature of this process, compelled to overdo its work, and to preserve finally too much energy within the star.

Now, by this gradual overheating of the inner layers the vertical temperature-gradient must increase more and more, until it reaches a degree of steepness at which the permanence of a mechanical equilibrium becomes impossible. In such a case the overheated gaseous matter will force its way outward and will break through the "cloak" of absorbing elements above it. But the overheated matter will not at once obey its molecular impulse to escape into higher levels. We must remember that there exists a powerful system of convection currents between the interior and the surface of the sun, and that the overheated particles may for some time be swept along the paths of these currents and may thus be forcibly detained in levels inconsistent with their increased temperature, so that their state of equilibrium is rendered unstable. This will produce a tension which increases in course of time until the upward tendency of the overheated particles becomes strong enough to overcome the resistance of the currents. At such a critical moment even a slight disturbance will be sufficient to induce the upward motion so long restrained, thus giving rise to a solar eruption. The cause of a solar outburst is therefore to be found in the temporary existence of an excessively great vertical temperature-gradient caused by progressive cooling of the outer atmospheric layers and the ensuing overheating of the inner photospheric layers.

From this exceedingly simple principle we are able to deduce an analytical demonstration of the periodicity of solar phenomena, which explains all the characteristics of the sun-spot curve hitherto observed. Obviously, the problem consists in demonstrating the changes in the amount of outward radiation which are caused, on the one hand, by the increase of absorptive power of the atmosphere in consequence of its progressive cooling, and, on the other, by the reduction of absorptive power of this same atmosphere in consequence of the "clarifying" action of eruptions which, by breaking through the "veil," diminish the number of cooled absorbing elements at the localities of eruption. I shall not enter upon this part of my investigation in the present note beyond stating that it is a simple application of Bouguer-Lambert's formula for the extinction of light and heat in an absorbing medium. The energy ϑ of the radiation leaving the upper limit of the atmosphere is found by the differential equation

$$\frac{d^2\vartheta}{dt^2} + \alpha\frac{d\vartheta}{dt} - \alpha\beta\vartheta = 0,$$

where t denotes the time reckoned from the moment when the photospheric layer a_n has attained its state of thermal equilibrium, and α and β represent constants, the former of which depends on the rate of cooling of the atmosphere, the latter on the action of the eruptions.

The integral of this equation will thus give us the changes in the radiating power of the sun toward a point in the universe. Considering that the intensity of the dynamical phenomena at the solar surface must depend on the excess of energy preserved to the sun beyond what he requires for the maintenance of thermal equilibrium at a_n, we arrive at the following theoretical equation for the frequency of eruptions and spots:

$$r = a\left[1 - e^{\lambda_1 t} + \frac{e^{\lambda_1 p} - 1}{1 - e^{\lambda_2 p}}\left(1 - e^{\lambda_2 t}\right)\right]$$

where p is the period and

$$\lambda_1 = -\tfrac{1}{2}\alpha + \sqrt{\tfrac{1}{4}\alpha^2 + \alpha\beta}$$
$$\lambda_2 = -\tfrac{1}{2}\alpha - \sqrt{\tfrac{1}{4}\alpha^2 + \alpha\beta}$$

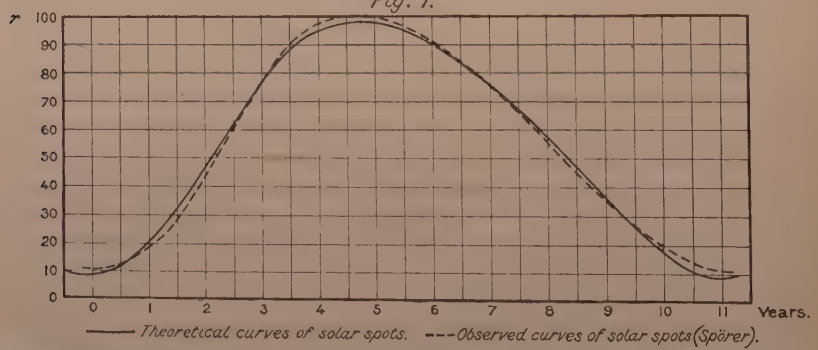
It is readily seen that r starts from zero at the moment $t=o$, and that it reverts to zero at the moment $t=p$. Between these two moments r attains a maximum, and we find the time when this occurs from the equation.

$$e^{(\lambda_1 - \lambda_2)t_m} = \frac{\lambda_2}{\lambda_1}\frac{1 - e^{\lambda_1 p}}{1 - e^{\lambda_2 p}}.$$

Now, it can be shown that the right-hand side of this equation is under all conditions $< e^{(\lambda_1 - \lambda_2)\frac{p}{2}}$, and this the more so the greater the difference between λ_1^2 and λ_2^2. Hence we deduce $t_m < \frac{1}{2}p$; i. e., the ascent from zero to the maximum must take place in an interval of time shorter than half the period. This constitutes the first theoretical proof of the well-known property of the observed spot-curve that the ascent is steeper than the descent.

To give some idea of the accuracy with which the above theory can be made to represent the observed facts, I subjoin a plate (fig. 1) in

Fig. 1.



which the spot-curve, resulting from theoretical considerations, is compared with Spörer's curve derived from observation. A full description of the method by which the theoretical curve has been obtained will be given in a paper shortly to be published as part of the first volume of the Annals of the Royal Observatory, Edinburgh.

The theory also accounts satisfactorily for the existence of a "great" period of solar phenomena. This greater cycle is brought about by the influence of the surface fluctuations of temperature described above on the intensity of the convection currents which regulate the interchange of heat between the interior and the surface. It is inconceivable that in a gaseous body like the sun, governed by a gigantic convection, changes of temperature of parts of its mass can be confined merely to the surface. Hence we must conclude that the distribution of temperature throughout a considerable part of the sun's bulk will be more or less affected by the fluctuations of temperature at the surface, and that, consequently, the intensity of the system of convection currents, which depend on this distribution of temperature, must undergo variations similar to those exhibited by the dynamical phenomena at the surface. Now these variations must react on the development of eruptions and spots. If the currents are weak—viz, if the transfer of heat from the interior to the surface is comparatively small—the cooling of the atmosphere must proceed rapidly, and hence the development of eruptions, which are a direct consequence of this process of cooling, must be energetic. At such times we have, therefore, to expect solar cycles with a powerful display of dynamical phenomena. If, on the other hand, the currents are intense—viz, if the heat supply from the interior is vigorous—the rate of atmospheric cooling will be small, and we have then to expect cycles with only a weak development of surface phenomena.

Since the quantity α depends on the rate of cooling of the atmospheric layers, it will attain high values at times when the spot development is powerful, and vice versa. Now, the greater α the greater will be the difference between λ_1^2 and λ_2^2, and, consequently, the earlier must the time of maximum, t_m, occur. Hence the position of the maximum in the spot period relatively to the preceding minimum must depend on the greater or less vigor of spot development during the cycle, inasmuch as the time of maximum must be the more in advance of the center of the period the greater the display of the dynamical phenomena. This important conclusion, arrived at by purely theoretical considerations, is amply corroborated by the facts. I refer in this respect to a recent publication of Dr. W. Lockyer, in which this peculiar shift of the maximum is pointed out as a feature of the observed spot curves.

Professor Wolfer, of Zurich, in the Monthly Weather Review of April, 1902, has also verified this peculiar theoretical result by a thorough discussion of the sun-spot observations from 1749 to 1901. "Only one result," he says, "which Dr. Lockyer has brought out is certain, and one which was also demonstrated by Dr. Halm, both from the observed facts and as a consequence of his new theory of the periodicity of the solar phenomena, namely, * * * that a maximum

follows a minimum quicker in proportion as the maximum is higher. * * * That the interval between minima and maxima depends intimately upon the intensity of development of the spots during that period would seem, therefore, to be quite certain, according to Lockyer's and Halm's investigations."

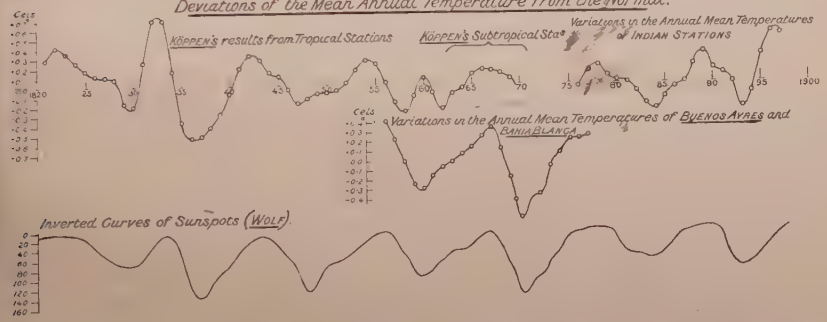
In this connection another interesting consequence of the theory may be mentioned. The above expression for r, as already pointed out, shows that the theoretical spot-curve, after having passed through a maximum, returns to zero when $t=p$. At this moment the status quo ante appears to be reestablished, inasmuch as the photospheric layers, by the assistance of atmospheric reflection, once more receive an exact compensation for their loss of energy sustained by outward radiation. If the opacity of the absorption layers above the photosphere could henceforth be supposed to remain constant, a repetition of spot-activity would be impossible. But since the cooling of these absorptive layers, being the necessary consequence of deficient contraction, is bound to proceed, it must eventually lead to a new sequence of phenomena similar to those of the previous cycle. The principal condition for the initiation of a new spot cycle must therefore be sought in the rate of cooling of the outer atmosphere at the moment of the reestablishment of thermal equilibrium in the photospheric layers. If the cooling proceeds rapidly the overheating of the inner layers will be indicated by a comparatively early renascence of eruptive activity. If, on the contrary, the cooling progresses slowly a more considerable interval of time will elapse before the state of unstable equilibrium favorable to the formation of new eruptions and spots can make its appearance. In the first case the minimum will be of short duration and the cycles will follow each other in rapid succession, whereas in the second case the minimum will appear protracted and the distance between consecutive cycles lengthened. In other words, the length of the period must depend on the rate of cooling of the atmospheric layers. Hence, from what has been said above, it must also vary with the intensity of spot development. Cycles exhibiting excessive spot activity must have less extended minima and must therefore be of shorter duration than others distinguished by a feeble display of dynamical activity. This consequence of the theory, too, appears to be confirmed by the observations. Thus the mean length of period of the cycles 1766.5—1775.5—1784.7 and 1833.9—1843.5, during which the display of spots was far above the average, embraces not more than 9.3 years, while the feebly developed cycles 1784.7—1798.3—1810.6 show a mean period of no less than 13.0 years.

The object of this brief abstract being merely an exposition of the main principles upon which I have ventured to build a new solar theory, I shall not enter upon its various applications to the phenomena connected with the periodic changes in the display of forces at the

sun's surface. In this respect the theory will be submitted to an exhaustive test in my paper in the Annals. In one important point it involves a radical deviation from the views hitherto held. So far investigators have almost unanimously adhered to the traditional view that an increase in the dynamical forces at the sun's surface indicates at the same time an augmentation of his light and heat radiation into the universe. A theory founded on this assumption would have to account not only for the extra expenditure of force into space, but also for the simultaneous increased development of force in the sun. But in the theory here proposed the exactly opposite conclusion is arrived at. Here the forces which we see acting on the sun are called into existence by the accumulation of such parts of his radiating energy as have been prevented from being thrown off into the universe. Thus, a surplus of energy working on the sun means a deficit of energy communicated to space.

It will be important, then, to ascertain how far this conclusion can be verified by observed facts. Modern researches seem, indeed, to

Fig. 2.



corroborate this theoretical result. If the theory be true, the temperature of the solar layers inside the absorbing atmosphere should be higher at the maxima than at the minima of solar activity, while the temperature of a body in space, which receives its heat from the sun, should vary inversely. In proof of the first conclusion I may refer to Sir Norman Lockyer's results with regard to the behavior of the lines widened in the spectra of sun spots, from which he infers that the matter composing the spots must be of higher temperature at the times of maxima. The second conclusion, on the other hand, is corroborated by all the more important researches which have recently been made regarding a connection between the changes of terrestrial temperature and solar activity. Of some of these I subjoin the main results in figure 2, which exhibits the observed changes in the mean annual temperature at tropical and subtropical stations and the corresponding variations of solar activity. It will be seen that for the whole period from 1821 until 1898 the temperature curve follows most accurately the fluctuations of the inverted spot curve, thus so far proving

the validity of the second conclusion, that space receives less heat at the maxima that at the minima of solar activity.

The solar theory here advanced is based on the assumption that the sun is a "cooling" star, viz, that his contractile force is not sufficient to compensate for his loss of energy by radiation. Now strong reasons can be adduced in favor of the assertion that the sun's mass must be mainly gaseous. But it has been urged by astronomers whose opinion on this point may claim earnest consideration, that, in accordance with a well-known theorem first enunciated by Lane, the temperature of a gaseous body should rise through shrinkage. The assumption here advocated would therefore appear to be in opposition to Lane's law. It must be borne in mind, however, that Lane's theorem supposes the conditions of a perfect gas. The question then arises as to whether this perfect state can be assumed to exist in the gaseous bulk of the celestial bodies. To make the question clearly intelligible, I shall first have to point out the main difference between the so-called perfect gaseous state and the gaseous state as we actually observe it. On this point I quote a few passages from Professor Andrews's important treatise in the Philosophical Transactions for 1876, Part II, pages 448–449:

1. In the ideal, or, as it is commonly called, the perfect gaseous state matter would obey implicitly the external forces which act upon it, the volume being always inversely as the forces externally applied. In this state it would neither offer resistance to volume[a] nor, from the action of internal attractive forces, would it undergo a greater diminution of volume than that due to the external pressure.

2. In the gaseous state, as we observe it, there are two distinct causes of internal disturbance whose results are directly opposed, and, according to the nature of the gas and the conditions of pressure and temperature, sometimes the one and sometimes the other predominates. One of these disturbances is due to the action of internal forces tending to produce a diminution of volume; the other is due to molecular conditions producing a resistance to diminution of volume other than that which occurs in a perfect gas.

We have, then, to consider three possible conditions: Either the gases in the sun are in that ideal state mentioned under (1), which is characterized by the rigorous fulfillment of Boyle's law; or (*a*) the molecules attract each other and thereby enhance the diminution of volume under increasing pressure; or (*b*) the molecules repel each other and thereby counteract the diminution of volume. Now, with regard to the attractive molecular forces, the researches of Clausius, van der Waals, and many other physicists, have shown conclusively that they diminish with increasing temperature. At ordinary temperatures all the gases, except hydrogen, show a preponderance of molecular attraction. If the temperature is raised, the mutual attractive influence of the molecules becomes smaller, and the gas

[a] By resistance to change of volume is to be understood a resistance from internal causes whereby the gas undergoes a less diminution of volume under increased pressure than would occur in the case of an ideal gas obeying Boyle's law.

approaches a state in which attraction is counterbalanced by repulsive forces between the molecules. When this state is reached the gas would appear to obey Boyle's law, because the molecular forces, to which a deviation from the law is due, neutralize each other. But from this behavior of the gases at low temperatures we may not yet conclude that an augmentation of temperature will more and more approach the gas to its ideal state as a limiting condition, and that consequently the incandescent gases in the sun must be in the perfect condition which was assumed by Lane when he derived his remarkable law. Such a conclusion would take no account of the possibility of an increase in the repulsive molecular forces with rising temperature. That indeed the perfect state is not the final state at which the gas arrives when its temperature is raised is clearly shown in the case of hydrogen.

The researches of Wroblewski have demonstrated that at very low temperatures hydrogen behaves like the other gases, showing a preponderance of molecular attraction. But already at 0° Celsius the gas exhibits the predominating influence of repulsive forces, which become more and more pronounced when the temperature rises. In a yet unpublished paper I have investigated, for a number of gases, the behavior of the molecular forces with changing temperature. By a simple modification of the equation of van der Waals I have succeeded in representing the isothermal curves of these gases up to the highest pressures hitherto attainable (3,000 atm.). The new equation of state, which is in accordance with Clausius's equation of the virial, enables us to study the influence of temperature on the attractive and repulsive molecular forces. In all cases the attractive forces have been found to diminish with increasing temperature, a result in accordance with the outcome of the researches of Clausius and van der Waals. But the repulsive forces, or to use Andrews's expression: "The forces which tend to produce a resistance to diminution of volume," appear to increase very rapidly when the temperature is raised. The investigation leads to the conclusion that at the temperature of the sun the preponderance of repulsive forces between the molecules of the gases must be very considerable. But it can be shown that under such conditions Lane's law loses its validity, so that a celestial body, although gaseous, may shrink under loss of temperature. This would remove an objection to the solar theory here advanced, which otherwise might be urged on the ground of its being in opposition to a theorem held by many to constitute one of the fundamental laws in the evolution of stars.

An objection may also be raised against the assumption that solar eruptions are real outbursts of matter into the higher regions of the solar atmosphere. To many astrophysicists it appears difficult to account for the enormous velocities exhibited by these phenomena on

the assumption of their representing real displacement of matter. It has been urged that the speed with which matter can be thrown up can not exceed the velocity of sound, but that the maximum speed which can be reasonably assigned to the propagation of sound in the incandescent gases at the sun's surface falls considerably short of the velocities observed in solar prominences. Here, however, we must again bear in mind that the computed velocities of sound which have been used as an argument against the eruption theory are based entirely on Boyle's law. If repulsive molecular forces are taken into consideration, the velocity of sound appears to be greater than in the case of a perfect gas. In fact, it is then no longer possible to assign an upper limit to the velocity of the sound wave, and hence this argument against the reality of the displacement of matter in solar eruptions loses its force.

As I shall demonstrate in my paper, a careful investigation of the behavior of gases at such temperatures as we may obtain in our laboratories, points conclusively to the fact that at solar temperatures gaseous matter must be far from the ideal state to which Boyle's law refers. Many of our views, hitherto based on this law, may have to be altered, but the changed aspect only removes serious difficulties without introducing others. I have found it advisable to add these few remarks on the state of gaseous matter in the sun to the original text of my investigation, as printed in Nature, February 13, 1902, in order to show briefly that the assumption upon which this solar theory mainly depends, viz, that our sun belongs to the class of "cooling" stars, is reconcilable with the gaseous constitution of his mass.

AN EXPERIMENTAL INVESTIGATION OF THE PRESSURE OF LIGHT.[a]

By Peter Lebedew.

Kepler was probably the first (in 1619) to attribute the form of comets' tails to a repulsive force from the sun, and to explain this repulsion as the result of the pressure exerted by the sun's rays on the matter in the tail. The same phenomenon also led Euler, in 1746, to ascribe a pressure to the solar radiation, and in 1754 De Mairan made the first attempts to test these ideas experimentally, but he did not obtain a positive result.

A dual theoretical basis for the pressure of radiation was independently and almost simultaneously given by Maxwell in 1873, as a consequence of the magnetic theory of light, and by Bartoli in 1876, as a consequence of the second law of thermodynamics.

If a beam of parallel rays is normally incident on a plane surface, the amount of the Maxwell-Bartoli light-pressure p is determined if we know the quantity of energy E received per second, the reflecting power ρ of the surface, and the velocity v of light. For then

$$p=\frac{E}{v}(1+\rho),$$

where ρ varies between 0 for an absolutely black surface and 1 for a perfectly reflecting surface.

This pressure is very small; for solar rays falling normally at the earth's distance upon a square meter, the pressure exerted is 0.4 mg. for a black surface and 0.8 mg. for a mirror.

In the experimental investigation of the pressure of light two large sources of disturbance arise, the one due to the well-known radiometric forces discovered by Crookes and the other to convection in the residual gas. It is possible, however, to diminish these disturbing forces and to make their effect on the observations harmless, if the experiments are made with very thin metal vanes and the exhaustion is carried as far as possible by using a mercury pump and condensing the mercury vapor by freezing mixtures.

[a] Reprinted, by permission, from The Astrophysical Journal, January, 1902. Translated from an abstract communicated by the author, of his extended paper in Annalen der Physik, VI, 433–458, 1901.

Without entering into the details of the experimental arrangements, the principle of the method employed may be briefly explained as follows: A torsion thread hangs in a highly exhausted bell jar and carries a vertical glass rod. Thin disks of 5 mm. diameter, of the metal to be investigated, are attached to this rod at a distance of 10 mm. from its axis. If the radiation from an arc lamp is concentrated on one of the disks the incident radiation will exert a pressure upon it, and it will retire until the pressure due to radiation is balanced by the torsion of the glass thread; the angle of torsion is measured by a mirror and scale as for a galvanometer. This observation permits the determination of the absolute magnitude of the pressure (in dynes) if the directing force of the torsion thread is measured in absolute units by one of the well-known methods.

In order to compare the observed pressures with those computed, according to Maxwell and Bartoli, from the amount of energy incident and the reflecting power of the vane used, the same beam of light was directed upon a circular aperture of exactly the same size as the vane, and the rays passing through were caught by a calorimeter. If we divide the quantity of energy incident per second, as measured by the calorimeter, by the velocity of light, we obtain the amount of pressure in dynes exerted by the light upon a perfectly absorbing body, according to Maxwell and Bartoli.

The measurements which were made repeatedly and with different apparatus yielded accordingly the following results:

Vane used.	Radiation observed.	Pressure computed.
Black platinum plated	1.1	1.0
Bright platinum	1.8	1.6
Bright aluminum	2.0	1.8
Bright nickel	1.4	1.6

For such complicated and difficult measurements a better agreement between observations and computation can not be expected. A discussion of the possible errors of observation shows that they are considerable, but that within the limits of error the existence of the light pressure of Maxwell and Bartoli are quantitatively confirmed.

This result is of importance to astrophysics as furnishing a much simpler explanation of the repulsive force of the sun than the hypothetical ones of electrical charges. A firm basis, amenable to computation and assured by experiment, is thus given to the view expressed by Kepler.

PHYSICAL INSTITUTE, *Moscow, November, 1901.*

COMETS' TAILS, THE CORONA, AND THE AURORA BOREALIS.[a]

By Prof. JOHN COX,
McGill University.

There is undeniable fascination about a theory which includes within its sweep the time-honored problems of astronomy connected with comets' tails and the reason why they point away from the sun; the solar prominences and the corona; the source of the light by which the nebulæ shine; the origin and structure of meteor swarms; and the aurora borealis; besides solving incidentally half a dozen minor outstanding mysteries of the heavens.

Such a theory has been advanced by Sweden's distinguished chemist and physicist, Svante Arrhenius, in a paper published in the Physikalische Zeitschrift for November, 1900. Its main points were briefly mentioned with approval by no less an authority than Prof. J. J. Thomson at the end of his captivating article on "Bodies smaller than atoms" in the August number of the Popular Science Monthly. All the physical principles on which Arrhenius relies, with one exception, are explained at length in that article, and are now very generally accepted. We may therefore say that the theory is based on "veræ causæ," and its accordance with known facts is so impressive when the comparison is made in detail that I venture to think the readers of Professor Thomson's article will be interested in a more complete statement of Arrhenius's views than time permitted him to give.

Let us begin by taking stock of the physical principles already to hand. We know (Professor Thomson's paper) that corpuscles, about 1,000 times smaller than hydrogen atoms, and each bearing a charge of negative electricity, are discharged with high velocity:

(1) From the negative electrode in a Crookes tube (cathode rays).
(2) From hot bodies, such as glowing metals.
(3) From cold metals under the influence of ultra-violet light.
(4) From the radio-active substance radium.

Again we know that these corpuscles, or ions, in passing through a gas produce other ions by collision with the molecules of the gas, and that the negatively charged ions are capable of serving as nuclei for the condensation of ordinary matter.

[a] Revised by the author from article in Popular Science Monthly, January, 1902.

COMETS' TAILS.

The single new principle introduced by Arrhenius arises in connection with the problem of comets' tails.[a] Astronomers have always felt that the phenomena exhibited by these strange objects could only be accounted for by making the sun the seat of a violent radial repulsive force, but were entirely at a loss to account for this repulsion. So long as light was supposed to consist of myriads of corpuscles discharged with a speed of 186,000 miles per second, it was easy, with Kepler, to regard the corpuscles as carrying with them in their rush the materials vaporized from the comet by the heat of the sun. But the establishment of the wave theory of light put an end to this idea. Thus Newcomb says (Popular Astronomy): "If light were an emission of material particles, as Newton supposed it to be, this view would have some plausibility. But light is now conceived to consist of vibrations in a ethereal medium; and there is no known way in which they could exert any propelling force on matter!"

Now, Arrhenius points out that according to the electro-magnetic theory of light a ray of light does exert a pressure on any surface on which it impinges. Maxwell not only proved this in his original publication of the theory in 1873, but showed how to calculate its value.[b] With the known constants of solar radiation he found that sunlight at the surface of the earth should exert a pressure of 0.592×10^{-10} grams on every square centimeter. This is too small a force to be detected, though it has been looked for.[c]

[a] This principle was first suggested as an explanation of comets' tails by P. Lebedew in 1891 (Wied. Ann., 45, p. 292), where it is pointed out that Maxwell's formula can only be applied strictly to a perfectly absorbing black body whose dimensions are small compared with the wave length of the incident light.

[b] Maxwell's formula was deduced on thermodynamical grounds by Bartoli (1876; see also Exner's Repert. d. Phys., 21, p. 198, 1885), Boltzmann (Wied. Ann., 22, pp. 31, 291; and 31, p. 139, 1884), and Galitzine (Wied. Ann., 47, p. 479).

[c] Until the appearance of Arrhenius's papers (Phys. Zeitschrift, Nov. 10 and 17, 1900) all attempts to detect the pressure of light experimentally had failed, since the effect to be looked for had been masked by convection and radiometric effects of much greater magnitude in the high vacua employed. But immediately afterwards it was successfully measured by Lebedew (Drude, Ann., 6, p. 433, 1901) and by E. F. Nichols and G. F. Hull (Physical Review, Nov., 1901, p. 397), employing different methods, but in both cases reaching results which accord with the calculated values within the limits of error of the observations.

Arrhenius applied the formulæ for comparatively large and perfectly absorbing spheres to particles ranging down to molecular dimensions which could not be regarded as absorbing. K. Schwarzschild (Münch. Ber.. 31, pp. 293–338, 1901), employing Spherical Harmonic Series, has given a complete mathematical discussion of the problem for perfectly reflecting spheres of any size. He finds that the pressure reaches a maximum when the diameter of the particle is one-third of a wave length, and then falls off rapidly; but that this maximum pressure (about 18 times the value of the solar gravitation) is all that is required for Arrhenius's theory. In fact, the agreement with the numbers quoted from Bredichin in the text, in ignorance of Schwarzschild's analysis, is curiously exact.

But at the surface of the sun the pressure would mount up to 2.75 milligrams per square centimeter. On the other hand, a cubic centimeter of water, which weighs 1 gram at the surface of the earth, would weigh 27.47 grams at the surface of the sun—i. e., the attraction of the sun would draw it inward with about 10,000 times the force with which the sun's light would tend to drive it away.

Very different is the case if, instead of a cubic centimeter, we consider a much smaller cube. The pressure on its base would fall off as the square of its edge, but the weight would diminish as the cube. There must come a point at which the pressure of the light would just balance the weight; and still smaller particles would be driven off with a force greater than their weight. They would behave, in fact, as if gravity had become negative.

For example, a cube of water measuring one-thousandth of a millimeter (10^{-4} cm.) in the edge would weigh 27.47×10^{-12} gms.; and the pressure of light on its base would be $2.75\times10^{-3}\times10^{-8}$, $=27.5\times10^{-12}$ gms.—i. e., slightly more than its weight.

In measuring wave lengths of light physicists denote one-thousandth of a millimeter by the symbol μ. The critical value of the edge of a cube of water, i. e., the value for which its weight is exactly neutralized by the pressure of light at the sun's surface, is thus approximately μ. For a spherical drop the critical diameter may be calculated to be 1.5 μ for water. For other substances the critical value is inversely proportional to the specific gravity.

A similar effect of extreme minuteness is familiar to us as the explanation of the long time required by very small particles to settle through the atmosphere, amounting to many months in the case of the finely-divided dust thrown up during the eruptions of Krakatoa; but the resistance to suspended dust particles can never exceed their weight, since it is only called forth by the motion produced by the weight itself. The pressure of light now considered may enormously exceed the weight, provided the particles are small enough.

From the motions, and especially the curvature, of comets' tails the magnitude of the repulsive forces to which they are subject may be calculated. Thus Bredichin finds in four instances that the repulsion must have been about 18.5, 3.2, 2, and 1.5 times the sun's gravitational attraction. Now, the vapors emitted by comets are largely hydrocarbons of specific gravity about 0.8. To account for these repulsions on Arrhenius's principle the drops must have had diameters of 0.1 μ, 0.59 μ, 0.94 μ, and 1.25 μ, respectively. In another case, where the tail curved toward the sun, Bredichin found the repulsion to be 0.3 times gravity. This would indicate particles of diameter 6 μ. Particles of this order of magnitude, and far smaller, are familiar enough to us, especially in combustion and in the early stages of condensation.

The theory suggested is, then, as follows: As the comet approaches the sun the intense heat causes a violent eruption of hydrocarbon

vapors on the side toward the sun. The hydrogen boils off and the vapors condense into small drops of hydrocarbons with higher boiling points, or ultimately solid carbon is thrown out, finely divided as in an ordinary flame. The largest of these particles fall back to the comet, or, if they are not condensed till at a great distance from it, they form tails turned toward the sun. The smaller are driven rapidly from the sun by the pressure of its light, with a speed depending on their size, and form the ordinary tails pointing away from it. That particles of different sizes should be formed from the same comet is natural, since the comet is likely to be formed of heterogeneous materials and there must be great variety in the circumstances of condensation. Thus the comet of 1744 had no less than five tails of different curvature. Occasionally the calculated repulsion on the same tail is not found to follow exactly the law of the inverse square of the distance from the sun throughout its whole length. This puzzling circumstance is at once explained if the particles should for any reason change their state of aggregation, and consequently their size, during their headlong career. In the light of this theory the following passages will be found very suggestive.

Herschel, Outlines of Astronomy (p. 376):

"It is for the most part after thus passing the sun that they shine forth in all their splendor, and that their tails acquire their greatest length and development, thus indicating plainly the action of the sun's rays as the exciting cause of that extraordinary emanation."

Again (p. 566):

"The tail of the great comet of 1680 immediately after its perihelion passage was found by Newton to have been no less than 20,000,000 leagues in length and to have occupied only two days in its emission from the comet's body—a decisive proof this of its being darted forth by some active force, the origin of which, to judge by the direction of the tail, must be sought in the sun itself."

Now, a particle with one-half the critical diameter would in the course of traveling from the sun's surface to a distance equal to his radius acquire a speed of 430 kilometers per second. With this velocity it would cross a space equal to the diameter of the sun, 865,000 miles, in less than an hour. In comets' tails we probably have to do with particles having less than one-eighteenth of the critical diameter. Such particles would cover the same distance in less than four minutes. With a force many times the sun's attraction driving them into space, they would make little of 20,000,000 leagues in two days; whereas if this were to be accomplished against gravity the velocity of projection required might well stagger the astronomers.

Referring to Halley's comet, Herschel says (p. 381):

"On the 2d of October (the very day of the first observed commencement of the tail) the nucleus, which had been faint and small,

was observed suddenly to have become much brighter and to be in the act of throwing out a jet or stream of light from its anterior part, or that turned toward the sun. This ejection, after ceasing a while, was resumed, and with much greater apparent violence, on the 8th, and continued with occasional intermittences so long as the tail itself continued visible. * * * These jets, though very bright at their point of emanation from the nucleus, faded rapidly away, and became diffused as they expanded into the coma, at the same time curving backward as streams of steam or smoke would do if thrown out from narrow orifices more or less obliquely in opposition to a powerful wind, against which they were unable to make way, and ultimately yielding to its force, so as to be drifted back and confounded in a vaporous train, following the general direction of the current.

"It seems impossible to avoid the following conclusions: First. That the matter of the nucleus of a comet is powerfully excited and dilated into a vaporous state by the action of the sun's rays, escaping in streams and jets at those points of the surface which oppose the least resistance. Second. That this process chiefly takes place in that portion of the nucleus which is turned toward the sun, the vapor escaping chiefly in that direction. Third. That when so emitted it is prevented from proceeding in the direction originally impressed on it by some force directed from the sun drifting it back and carrying it out to vast distances behind the nucleus, forming the tail. Fourth. That this force, whatever its nature, acts unequally on the materials of the comet. Fifth. That the force thus acting on the materials of the tail can not possibly be identical with the ordinary gravitation of matter, being centrifugal or repulsive, as respects the sun, and of an energy very far exceeding the gravitating force toward that luminary. This will be evident if we consider the enormous velocity with which the matter of the tail is carried backward, in opposition both to the motion which it had as part of the nucleus and to that which it acquired in the act of emission."

Again, describing the long, straight tail of the great comet of 1843, from which a lateral tail, nearly twice the length of the regular one, was shot forth in a single day, Herschel says:

"The projection of this ray, which was not seen either before or after the day in question, to so enormous a length (nearly 100°) in a single day conveys an impression of the intensity of the forces acting to produce such a velocity of material transfer through space, such as no other natural phenomenon is capable of exciting. It is clear that if we have to deal here with matter, such as we conceive it, viz., possessing inertia, at all, it must be under the dominion of forces incomparably more energetic than gravitation and quite of a different nature."

And finally (p. 406):

"There is beyond question some profound secret and mystery of nature concerned in the phenomenon of their tails. In no respect is the question as to the materiality of the tail more forcibly pressed on us for consideration than in that of the enormous sweep which it makes round the sun in perihelio, in the manner of a straight and rigid rod, in defiance of the law of gravitation, nay, even of the received laws of motion, extending (as we have seen in the comets of 1680 and 1843)

from near the sun's surface to the earth's orbit, yet whirled round unbroken, in the latter case through an angle of 180° in little more than two hours. It seems utterly incredible that in such a case it is one and the same material object which is thus brandished. If there could be conceived such a thing as a negative shadow, a momentary impression made upon the luminiferous ether behind the comet, this would represent in some degree the conception such a phenomenon irresistibly calls up. But this is not all. Even such an extraordinary excitement of the ether, conceive it as we will, will afford no account of the projection of lateral streamers; of the effusion of light from the nucleus of a comet toward the sun, and of its subsequent rejection; of the irregular and capricious mode in which that effusion has been seen to take place."

These passages give a vivid picture of the utter puzzledom of astronomers over difficulties which arise from precisely those phenomena which fit most naturally into the theory of Arrhenius.

THE PROMINENCES AND THE CORONA.

At the moment when the sun's disc is obscured in a total eclipse enormous red flames, sometimes curving over toward the sun and sometimes floating like clouds at heights up to 40,000 miles above his surface, are seen projecting over the region of sunspots, where the sun's eruptive activity is greatest; and silvery streamers with a radial structure form a lens-shaped envelope about the same region, often extending to a distance of several times the sun's radius. These are known as the prominences and the corona.

The sun must itself project vapors into space. When these condense, the drops will, if larger than the critical size, fall back to the sun, giving rise to the curved prominences; and if smaller, they will be driven off into space, and be seen as the streamers of the corona. Since the eruptions will not always be perpendicular to the sun's surface, the prominences will often exhibit parabolic curves, and the streamers may not always be strictly radial, though the greater part of this effect is to be attributed to the foreshortening under which some of them are viewed from the earth.

Those particles which have approximately the critical diameter will float as clouds, sustained by the pressure of light. This point is specially interesting, since it has been difficult to account for the maintenance of the cloudlike prominences without assuming the existence of a considerable atmosphere about the sun. Yet the comet of 1843 described 300,000 miles within a distance of less than one-third of the sun's radius from his surface with a velocity of 350 miles per second, and came out without having suffered any visible damage or retardation.

The corona has been as great a stumbling-block to astronomers as the comet's tail. Thus Newcomb (Popular Astronomy, p. 263) says:

"The corona is not a mass of foggy or milky light, but has a hairy structure like long tufts of flax. * * * Of this appendage we may

say with confidence that it can not be an atmosphere, that is, a continuous mass of elastic gas held up by its own elasticity. * * * What, then, is the corona? Probably detached particles partially or wholly vaporized by the intense heat to which they are exposed. * * * The difficult question which we meet is, How are these particles held up? To this question only conjectural replies can be given."

Three conjectures are then mentioned, of which we may note the first:

"That the matter of the corona is in what we may call a state of projection, being constantly thrown up by the sun, while each particle thus projected falls down again according to the law of gravitation. The difficulty we encounter here is that we must suppose velocities of projection rising as high as 200 miles per second constantly maintained in every region of the solar globe.

"The prominences are of two classes—the cloud-like and the eruptive. The first class presents the appearance of clouds floating in an atmosphere; but as no atmosphere dense enough to sustain anything can possibly exist there, we find the same difficulty in accounting for them that we do in accounting for the suspension of the matter of the corona."

Professor Young is frankly despairing:

"I do not know what to make of the corona. * * * By what forces the peculiar radiated structure of the corona is determined I have no definite idea. The analogies of *comets' tails and auroral streamers* both appear suggestive; but on the other hand, the spectra of the corona, the aurora borealis, the comets, and the nebulæ are all different, no two in the least alike. * * * Nor have I any theory to propose to account for the *certain connection between disturbances of the solar surface and of terrestrial magnetism*."

The words we have underlined in this passage have almost a Sophoclean irony to a reader acquainted with the further developments of Arrhenius's theory, to which we now turn.

THE ZODIACAL LIGHT AND THE GEGENSCHEIN.

Not only is the sun the source of those eruptions of ordinary matter which form the prominences, but we have every reason to be believe that he must emit streams of electrically charged corpuscles both directly, as a hot body, and indirectly, since the electrical discharges which, according to all terrestrial analogies, must accompany the violent chemical actions going on near his surface, will, when they take place in the higher and rarer regions of his atmosphere, give rise to kathode rays, and these, in turn, to Röntgen rays. As Professor Thomson says: "As a very hot metal emits these corpuscles, it does not seem an improbable hypothesis that they are emitted by that very hot body, the sun."

Now the negatively charged corpuscles are preeminently fitted to serve as nuclei for the condensation of the ordinary matter. Hence those particles of the latter which, having more than the critical diameter, fall back to the sun, will carry back a negative charge to him; while

those which have less than the critical diameter will carry a negative charge off into space. On both counts the corona will be left with a surplus of positive charge. The same arguments hold for the vapors emitted by the nucleus of a comet. Thus comets' tails should consist of negatively charged particles.

Let us follow the career of the particles launched into space. They proceed radially from the sun above the regions of sun spots with rapidly increasing speed, which, however, may be shown to approach a finite limit at a distance of about ten radii from the sun. If they encounter another body, such as the earth, they charge its outer atmosphere negatively, and when this charge reaches a certain value, it will begin to repel them. The oncoming rush will be deflected, and stream past the earth on each side in hyperbolic orbits. Far out in space they must sooner or later meet particles from other bodies, and, if by collision or aggregation they increase beyond the critical diameter, they will first lose speed and then drift back with ever increasing velocity past the earth, directly toward the sun. The space immediately behind the earth would be screened by her, and so be void of particles. Could we take our stand on the moon, we should thus see the earth attended by a faint double tail with a dark dividing line (so conspicuous a feature in comets), immediately behind it, pointing from the sun; and a similar, though perhaps fainter, tail, pointing toward him. Not only so, but the earth helps to form her own tail. For when the negative charge in the upper atmosphere is high enough, discharges are brought about by the powerful ultra-violet radiation from the sun, and particles are driven off radially from the earth on the side turned toward the sun, only to be drifted back with the other streams into the tail. The effect will be as if a sheaf of light projected from her toward the sun.

Compare with this the description of the zodiacal light (Newcomb, Popular Astronomy, p. 416):

"This object consists of a very soft faint column of light, which may be seen rising from the western horizon after twilight on any clear winter or spring evening; it may also be seen rising from the eastern horizon just before daybreak in the summer or autumn. It really extends out on each side of the sun, and lies nearly in the plane of the ecliptic. * * * Near the equator, where the ecliptic always rises high above the horizon, the light can be seen about equally well all the year round. * * * It is due to a lens-shaped appendage of some sort surrounding the sun, and extending out a little beyond the earth's orbit.

"The nature of the substance from which this light emanates is entirely unknown. * * * Professor Wright, of Yale College, finds its spectrum to be continuous. Accepting this, we should be led to the conclusion that the phenomenon in question is due to reflected sunlight, probably from an immense cloud of meteorites, filling up the space between the earth and the sun."

The difficulty in this view is that the orbits of such swarms of meteorites as are known to us are distributed irregularly with regard to the ecliptic. On the other hand, Arrhenius's streams of particles, when near enough to be visible, necessarily lie in or near the ecliptic, as required by observation. More than this, the particles emitted by the earth herself should be most abundant over those regions which have been exposed for many hours to the sun. Now it has been observed that the zodiacal light is stronger on what Arrhenius calls the "evening side" of the earth (i. e., that side which is in the act of turning away from the sun, and has the sun in the west) than on the "morning side."

Even at night, when the sun is below the horizon, faint reflections should reach us from the streamers behind the earth, and by an effect of perspective, these should have a maximum in the point opposite to the sun, where they will appear most dense. Let Professor Newcomb describe the Gegenschein:

"Another mysterious phenomenon associated with the zodiacal light is known by its German appellation, the Gegenschein. It is said that in that point of the heavens directly opposite the sun there is an elliptical patch of light, a few degrees in extent, of such extreme faintness that it can be seen only by the most sensitive eyes, under the best conditions, and through the clearest atmosphere. This phenomenon seems so difficult to account for that its existence is sometimes doubted; yet the testimony in its favor is difficult to set aside."

How is it that the moon does not exhibit such tails? The moon has no atmosphere, so that the particles which reach her give up their negative charge to her directly, and it spreads equally all over her surface. When in turn she herself discharges the particles, it will be uniformly in all directions, and she should appear surrounded with a uniform sheath. Possibly this sheath of cosmical dust affords the reason that in a lunar eclipse the shadow of the earth can be traced a short distance beyond the limb of the moon on each side.

THE AURORA BOREALIS.

Perhaps the most interesting application of Arrhenius's theory is his explanation of the Aurora. In a well-known experiment the streams of negative particles forming cathode rays in a Crookes tube are exposed to a magnetic field, when they are seen to describe helices round the lines of force. If the field is powerful enough they may thus be bent into a complete circle inside a moderately large tube.

Now the negative particles discharged from the sun arrive most thickly over the equatorial regions of the earth, which are most directly exposed to him. Long before they reach any atmosphere dense enough to excite luminescence, they are caught by the lines of force of the earth's magnetic field, which are horizontal over the equator, and have to follow them, winding round them in helices whose

radii are so much less than their height above us that the effect to a beholder on the earth is as if they moved along the lines of force. Over the equator there is little luminescence, for lack of atmosphere. But as the lines of force travel north and south they dip downward, making for the magnetic poles, over which they stand vertical. Soon the particles find themselves in lower layers of the atmosphere, comparable in density with our highest artificial vacua, and begin to give out the darting and shifting lights of the cathode ray. But this can only be at the cost of absorption, and by the time the denser layers of air are reached their energy is exhausted. Hence the dark circles round the magnetic poles from which, as from behind a curtain, the leaping pillars of the Aurora rise. From this point of view it is significant that Dr. Adam Paulsen, who has made a special study of the northern lights, found so many points of correspondence between them and cathode rays that in 1894 he was led to regard the aurora as a special case of the latter, though unable to give any account of their origin in the upper atmosphere, such as is supplied by Arrhenius's theory.

The most obvious test to which we can subject such a theory is to ask from it some explanation of the very remarkable periodic variations in the frequency of auroræ. If they are caused by streams of particles ejected from the sun, there should be some connection between the changes in the sun's activity, as indicated by the number of sun spots, and the number of auroræ observed. Again, since a negative charge in motion is (pace M. Cremieux) equivalent to a negative current, the passage of electrified particles through the upper atmosphere should affect magnetic instruments on the earth. Sun spots, auroræ, magnetic storms should therefore vary together.

It has long been known empirically that they do agree in a general way. Arrhenius's discussion of the mass of statistics of observed auroræ forms so striking an example of the "Method of concomitant variations" that at the risk of wearying the reader we shall give it in some detail.

1. Slow secular periods.—(*a*) Both sun spots and auroræ show marked maxima at the middle of the eighteenth and the end of the nineteenth centuries.

(*b*) Sun spots, auroræ, and magnetic storms go through a simultaneous increase and decrease in the well-known period of 11.1 years.

The source of these slow variations must be looked for in the little understood variations of the sun's activity.

2. Annual period.—The number of auroræ is greatest in March and September, and least in June and December; and the mean frequency for both hemispheres is somewhat less in June than in December.

Now the sun's activity, as indicated by the number of sun spots, is a minimum at his equator, the spots occurring principally in belts about

15° north and south of his equator. Since the streams of particles issue radially from the sun, the earth will be most exposed to them when she is most nearly opposite the active belts. But the earth stands opposite the sun's equator on June 4 and December 6, and is at her farthest north and south of it (7°), i. e., most nearly opposite the sun-spot belts, on March 5 and on September 3. Moreover, she is somewhat nearer to the sun in December than in June.

As between the two hemispheres, the same conditions apply as those which regulate the seasons, viz, altitude of the sun above the horizon, and length of time during which he remains above it daily. Auroræ should therefore be more frequent in summer than in winter, a result which is verified by the records. And just as the highest daily temperature occurs from two to three hours after midday, so we ought to find a daily maximum of auroræ about 3 p. m. It is not possible to verify this directly, since auroræ are not visible in daylight. But Arrhenius remarks (1) that the majority of them occur before midnight and not after it, which is so far in general agreement with the theory; (2) that Carlheim-Gyllenskiöld, discussing the observations made at Cape Thordsen in Spitzbergen during the winter of 1882–83, with a view to correcting the numbers recorded for the effect of daylight in concealing them, deduces a probable maximum for the number actually occurring at 2.40 p. m.

But though we can not observe auroræ in daylight we are not without resource, for even when invisible they give notice of their presence by disturbing the ordinary course of the records photographically taken in our magnetic observatories. In 1899 Van Bemmelen discussed the records of such magnetic storms taken in Batavia. He found that they show maxima in March and September, minima in January and June, and a daily maximum at 3 p. m., and minimum at 1 a. m.

3. Monthly variations.—It is only recently (1898) that the collection of statistics of auroræ published by Eckholm and Arrhenius has brought to light two curious monthly variations in their number.

One of these, with a variation of 20 per cent on each side of the mean, depends on the revolution of the moon in her orbit, showing in the northern hemisphere a maximum when the moon is farthest south of the equator, a minimum when she is farthest north; and vice versa for the southern hemisphere.

The explanation appears highly ingenious. It is as follows: The moon, being unprotected by an atmosphere, is charged by the streams of particles that reach her much as the outer layers of our own atmosphere are charged, and therefore, as we have good reason to believe, to a far higher negative potential than is observed at the surface of the earth. If so, she will seriously affect the number of auroræ at any place over which she stands, by lowering the potential gradient, and thus reducing the number of negative discharges in the highest regions of our atmosphere.

The other variation of some 10 per cent each way has a period of 25.93 days and affects both hemispheres alike. At first sight it is natural to refer this to the synodical time of revolution of the sun on his axis as determined by observations of sun spots. But this is 27.3 days. Remembering that the earth never departs more than 7° from the sun's equator, we should rather take the time of revolution of the equatorial belt for comparison. As estimated by the motion of the faculæ, this is 26.06 days, the equator moving faster than the sun-spot belts, and probably the time of revolution of the outermost layers, from which the particles stream, is yet a little shorter. The agreement with the period of the aurora (25.93 days) would thus be within the limits of error of the observations.

ATMOSPHERIC ELECTRICITY.

Let us now trace the effect of the auroræ on the earth's atmosphere. If they are really cathode rays on a grand scale, they must ionize the air; the negative ions will form centers for condensation, and sinking to the earth by gravitation, will charge it negatively, leaving the layers at moderate heights positively charged. This agrees with the results of recent observations made from balloons up to heights of 3,000 meters.

Since condensation will depend on the number of ions available for nuclei, we have at once an explanation of the curious fact that cloud formation in the upper atmosphere is more copious in years of frequent auroræ than when they occur rarely. In this connection another odd coincidence may be mentioned. When sun spots are numerous Jupiter shines with a white light; when they are few his light has a reddish tinge. Now, it is agreed that Jupiter is still at a high temperature. If, therefore, sun spots cause auroræ on Jupiter, and consequent cloud formation, we must see less of the heated interior in sun-spot years than we do when his cloud layers are not so opaque.

In 1899 Von Bezold showed that the daily variation of the compass over the earth's surface could be simply represented as follows: Imagine two points, one in latitude 40° N., and one in 40° S., to move round with the sun. Then it is as if the north end of the compass needle were attracted toward the northerly point and the south end toward the southerly. Remembering that the air immediately above the earth has a positive charge, we see that this effect would follow by Ampère's rule, if the sun's heat caused two air whirls, one in the northern and one in the southern hemisphere, over the places of highest temperature, the former rotating counter-clockwise, the latter clockwise. Such whirls would result from the sucking in of currents from the slower-moving north latitudes and the faster-moving south latitudes toward the mean latitude of 40°, in the northern hemisphere, and similarly for the southern. If this be the true explanation, then for a given frequency of sun spots the amplitude of the diurnal varia-

tion should increase by the same fraction of itself for all parts of the earth. Thus, if A' is the amplitude at a given place in a year of no sun spots, and A its value in a year for which Wolf's number expressing the relative frequency of spots is f, we ought to find $A = A'(1+\alpha f)$. Now, the value of the coefficient α comes out 0.0064 from whatever part of the world the observations be taken from which it is calculated.

METEORITES AND NEBULÆ.

To the man of science this discussion of terrestrial details will probably be the most convincing part of the evidence adduced by Arrhenius for his theory. But it is time to turn from it and follow with lagging imagination the destinies of those particles, by far the greatest number, which miss the earth and the planets and launch forth into interstellar space.

Many of them will meet similar streams ejected from other suns, and, overcoming the mutual repulsion of their negative charges by their mighty velocities, will clash together, like Lucretius's atoms, and unite to form larger masses. But this aggregation must have an end. For if, in the void of space, they are unable to get rid of their electric charges, the potential of the growing mass must rapidly increase, since the charge increases as the cube of the radius, being proportional to the total number of particles, while the capacity for holding electricity only increases as the radius itself. To put this in popular language, each particle brings to the account the whole charge it can bear on its surface; but in the mass, since electricity flies to the surface, only the outer parts of those particles which are actually in the surface can be useful in harboring the accumulating charge, and hence the electric pressure rises. When it becomes intense enough to prevent fresh particles from approaching, accretion will cease. Space will thus be sown with masses of moderate size, formed irregularly, particle by particle, in spite of repulsive forces. These are the meteorites which blaze for a moment in the upper air, or in rare cases reach the earth to puzzle philosophers with their porous structure.

Another multitude of the particles will at last reach other suns. For if in their wanderings they have united with others till they are beyond the critical size, they will be drawn in, and raise the charge of the bodies they reach, till they in turn discharge their streams into space.

In these we see the "greyhounds" of the abyss, engaged in distributing the materials of the universe, forever busied in a cosmic traffic by whose exchanges the stellar hosts are made more and more alike in constitution, whatever may have been their differences in the beginning.

For those myriads which are fated to escape all visible suns, far out in the "flaming bounds of space" the nebulæ lie in wait, spreading spider-like their impalpable webs across immeasurable breadths of sky.

Ever since the spectroscope showed that many nebulæ are gaseous, and yet shine by their own light, two problems have vexed the astronomers. How can they be hot enough to send light to us, and yet be held together against the expansive force of the heated gas by the feeble gravitation which such inconceivably diffuse masses can exert at their borders? If they are really at a temperature of not less than 500° C., so as to shine, or, indeed, if they are much above absolute zero, their own gravitation should not be able to prevent their speedy dissipation into space.

Again, why do they show the spectroscopic lines of so few gases, and those the lighter ones, such as hydrogen and helium?

According to Arrhenius, the nebulæ are cold, with the cold of empty space. Their light is due to the rain of negatively charged particles which, plunging into their outermost regions, give rise to electric discharges and make their gases shine as the gases in a vacuum tube. To this the intense cold is no bar, for Stark has shown that the intensity of light excited in a vacuum tube is greater the lower the temperature at which the experiment is tried. And this process should take place at the surface of the nebula, where the lighter gases would be found, the heavier settling inward. Hence the few lines found in the spectrum of a nebula, and the comparative brightness of the outlying parts, especially to be observed in the planetary and the ring nebulæ.

Such is Arrhenius's theory. It is too early, as yet, to pronounce any judgment upon it, but glancing back over the array of hitherto unexplained facts which fall into order, without forcing, at its touch, we must admit that it is at least plausible. It springs from a single principle, itself a necessary theoretical consequence of the accepted electromagnetic theory of light — viz, that light must exert a pressure which, in the case of small particles, may very greatly exceed their weight. By means of this principle in conjunction with recent views about the nature and properties of ions, which can all be experimentally verified, this theory gives a rational explanation of the astounding behavior of comets' tails; accounts for the "hairy" structure of the corona; shows us how the prominences can float where the existence of a supporting atmosphere is inadmissible; what is the origin of the zodiacal light and the Gegenschein; of "the certain connection" between sun spots and magnetic storms; of the aurora, and why it is subject to such complicated periodical variations; why meteorites are porous and limited in size; how the nebulæ shine in the absolute cold of interstellar space, and yet hang together; and why their constituents appear to be so restricted, while the suns among which they are strewn give evidence of most of the elements known on earth.

A theory which sweeps the astronomical horizon of so many mysteries must not only arouse our profound interest, but claim the respectful consideration of men of science.

"GOOD SEEING."[a]

By S. P. Langley.

Everyone who has used a telescope knows that our atmosphere is forever in pulsating motion, and troubling our vision of the heavenly bodies, during the most cloudless day or night, so that observatories are put even on high mountains, to get rid of the disturbances in this atmosphere, which tend to make the image of every object tremulous and indefinite, and to prevent what the astronomer terms "good seeing."

I desire to speak to the academy about a device which I have recently essayed for preventing this universally known and dreaded "boiling" of the telescopic image, a difficulty which has existed always and everywhere since telescopes have been in use, and which has seemed so insurmountable that I believe it has hardly ever been thought of as subject to correction.

Hitherto it has been the endeavor of astronomers, so far as I know, to secure a more tranquil image by keeping the air in the telescope tube, through which the rays pass, as quiet as possible, and for this purpose the walls of the tube have been made nonconducting, and extreme pains have been taken not to set up currents in the tube. With these precautions the "seeing" is perhaps a little better (but very little) than if none were used at all, the main difficulty having been always found insurmountable.

I have been led for some years to consider the conditions under which this "boiling" presents itself. It is not necessarily due to a high temperature of the external air, for the most perfect definition I have ever seen of any terrestrial object was obtained by me long since in the Harvard College Observatory at Cambridge, with its great equatorial telescope, when, on the hottest day that I ever knew in a New England summer, I directed it with a high power on the distant "south mark," which I expected to find almost indistinguishable from the "boiling." I remember my extreme surprise when, under a magnifying power of 300, I found the image as still as the lines of an engraving. This was an extraordinary exception to ordinary experience, and led me to take

[a] A paper presented to the National Academy of Sciences, November 12, 1902.

an interest in the subject. I have since pursued an inquiry to which this circumstance first directed my attention, and I have done so at all altitudes, at one time residing on Ætna for this purpose, noting that even on high mountains telescopic vision was so far from being always clear that it was sometimes even much worse than at sea level.

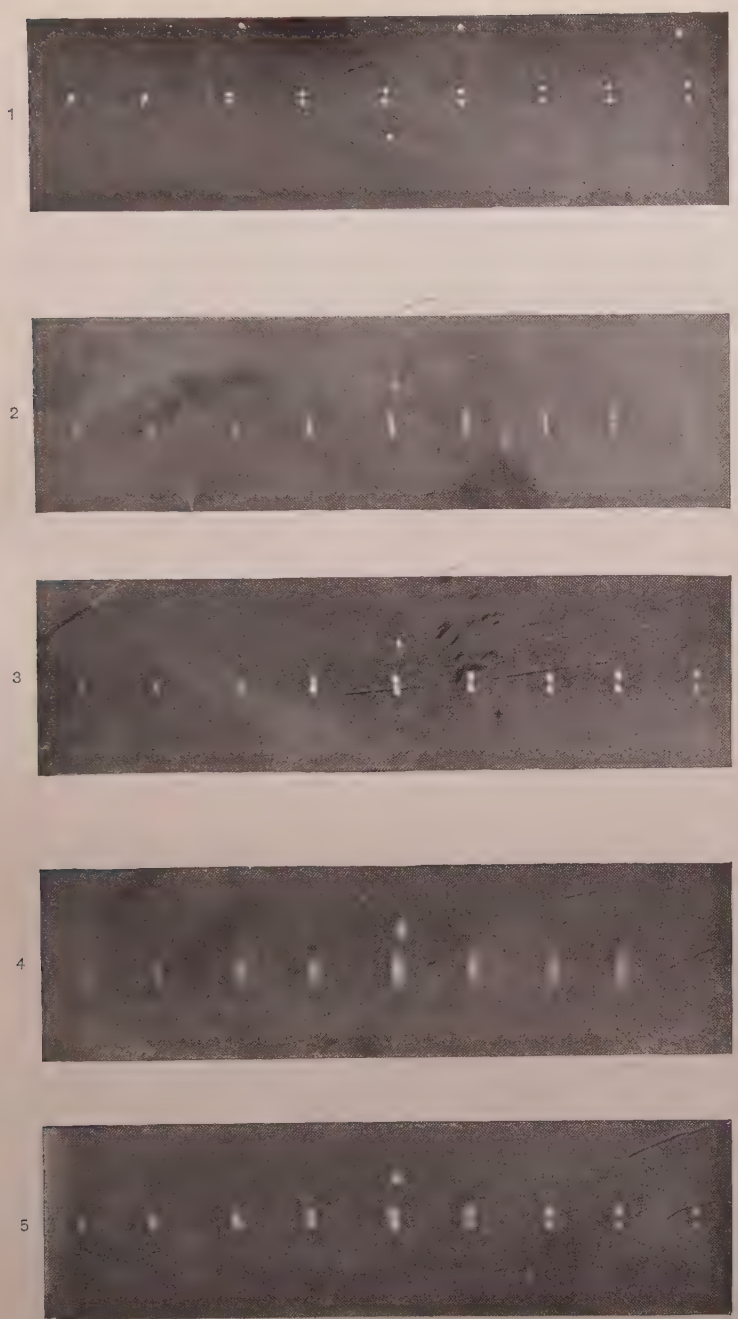
I have since come to the important conclusion that while the ordinary "boiling" is due to all the air between us and the sun or star through which the rays pass, the greater portion of it is due to the air immediately near us, probably within a few hundred yards or even feet from the telescope, and this has led me to ask whether it was not possible that some way to act upon this air could be found. Its nonuniformity leads to deformations of the image too complex to analyze here, which are caused not only by lateral vibrations of the cone of rays but by its elongation and contraction.

For this purpose I have, within the last few months, been making experiments at the Smithsonian Astrophysical Observatory: first with a horizontal tube having three successive walls with air spaces between, which was intended to give the maximum security which freedom from changes of temperature could afford. This observatory, being principally concerned with rays best studied in an image formed by reflection, has no large dioptric telescope, on which account these experiments have been made with a reflector. I have no reason to suppose, however, that they will not be equally successful with a dioptric telescope.

A large part of the "boiling" of the image is due to air without the tube, but a not unimportant part to the air within it; and in the preliminary experiments the air, kept still in the tube by treating it with the ordinary precautions, was found to have little effect on the ordinary "boiling" of the image, which so seriously prejudices the definition. An image-forming mirror, fed by a coelostat, was placed at the end of this triple-walled tube, which was itself sheltered by a canvas tent and contained the stillest air of the most uniform temperature which could be obtained. The "boiling" was but little diminished merely by inclosing the beam by this tube, which was only what had been anticipated from the ordinary experience of all astronomers.

The device which I had determined to try was one of a paradoxical character, for it proposed to substitute for this still air, which gave the usual troubled image, agitated air which it was hoped would give a still image.[a] For the purpose of this new experiment, the horizontal telescope using a reflector of 40 feet focus, fed by a coelostat through the above tube, was connected with a fan run by an electric motor, which was arranged to draw out the air from the inner tube at the same time that it forced air in at different points in its length, so as to

[a] I may mention here that my lamented friend, Henry C. Draper, once showed me that agitating the contents of a bisulphide of carbon prism improved its definition.



EXPERIMENTS ON ARTIFICIAL GOOD SEEING, SMITHSONIAN ASTROPHYSICAL OBSERVATORY.

No. 1. The object, a series of artificial double stars.
2. Image of No. 1, without stirring. } Exposure, three minutes.
3. Image of No. 1, with stirring. }
4. Image of No. 1, without stirring. } Exposure, four minutes.
5. Image of No. 1, with stirring. }

thus violently disturb and churn the air along all the path of the beam from the coelostat to the solar image.

This first experiment gratifyingly reduced the "boiling" and produced an incontestibly stiller image than when still air was used. As a further test, a series of artificial double stars was now provided, and the concave mirror, acting both as collimator and objective, brought the images to focus, where they were examined with an eyepiece. With the stillest air obtainable the images were not sharp, and only the coarsest doubles were resolvable. Then the blower was started and the definition immediately became sharp. Violently stirring the air in the tube, then, eliminates all or nearly all the "boiling" of the stellar image which arises within the tube itself when using ordinary still air. This experiment concerned the air within the horizontal tube only.

I have next taken up the solar image formed by the mirror in the above tube. This is clearly improved by the stirring. I have also wished to try a tube something like a prolonged dew cap, but which is arranged to be inclined toward the sun. The air in both can be stirred together, but experiment has not yet gone far enough to demonstrate whether it has, as is hoped, any superiority commensurate with the special mechanical difficulties involved.

I am not prepared to give quantitative estimates, which I hope to furnish later, but all observers to whom I have shown these early results on the sun have agreed, that if the "boiling" was not wholly cured, what remained was but a small fraction of that obtained with still air. I have not completed these experiments, which I am still pursuing at the observatory, but they seem to me to give promise of an improvement of universal interest to observers, which justified the making of this early announcement. I had hoped to have shown the Academy some photographs of the sun taken, first, in the ordinary way, and again, with the churned air, but the condition both of the sun and of the sky of late has prevented my obtaining them. I can, to my regret, only give here a photograph of the images of the artificial double stars as seen through ordinary conditions, as distinguished from those here mentioned, of artificial "good seeing."

ON THE RADIO-ACTIVITY OF MATTER.[a]

By Henri Becquerel, D. C. L., Ph. D.
Member of the Academy of Sciences, Paris.

The property possessed by certain bodies of emitting invisible and penetrating rays was unknown six years ago. The speculations brought about by the experiments of M. Roentgen led to the examination of material bodies to see if any of them had the power of emitting similar radiations; the phenomenon of phosphorescence naturally was first thought of, being a known method for the transformation and emission of energy. This idea, however, could not be applied to the phenomena with which we are occupied, but it was very fruitful. It led to the choice, among phosphorescent bodies, of the salts of uranium, of which the optical constitution is remarkable on account of the harmonic series of the bands of their absorbtion and phosphorescent spectra. It was while experimenting with these bodies in 1896 that I first observed the new phenomena which I am about to bring before you this evening. I have here the plates of the double sulphate of uranium and potassium, obtained by Lipmann's method, which I used for my first experiments.

After having placed one of these plates on the black paper which covered a photographic plate, and leaving it for several hours, I observed on developing the plate that the uranium salt had emitted certain active rays, traversing the black paper, as well as various screens interposed between the plate and the active body, such as thin sheets of glass, aluminum, copper, etc. I soon saw that this phenomenon had nothing to do with phosphoresence, or with any known method of excitation, such as luminous or electric rays, or any appreciable variation of temperature.

I had to deal, therefore, with a spontaneous phenomenon of a new order. The absence of any known exciting cause on a body prepared

[a] A discourse delivered in French before the members of the Royal Institution, London, Friday, March 7, 1902. Reprinted, by permission, after revision of text by Professor Becquerel, from translation in Scientific American Supplement, No. 1379, June 7, 1902. Illustrations from original article in Proceedings of the Royal Institution of Great Britain.

in the laboratory several years ago, caused me to think that the phenomenon would have been the same at any time it might have been observed; it should, therefore, be permanent, that is to say, there should not be any appreciable weakening after a very long time. This is, in fact, what I have proved during the past six years. I will show you the first proof I had of the spontaneity of the rays; these rays have traversed the black paper which covered the photographic plate, and a thin strip of copper in the form of a cross (fig. 1). Here, again, is the radiograph, made about the same time, of an aluminum medal, fig. 2; the unequal absorption of the different thicknesses has caused the appearance of the effigy thereon. After the very first observation I observed that the new radiations would discharge electrified bodies at some distance in the air, a phenomenon which gives us a second method for studying these rays; the photographic method is specially qualitative, while the electrometer furnishes numerical elements of comparison.

In the course of these first observations, I was led away from the path toward which later experiments brought me back by several facts, of which the following is the principal: Having protected a photographic plate by means of a sheet of aluminum 2 mm. in thickness, and having arranged on the aluminum several samples of phosphorescent powders, placed on separate plates of glass, and covered with small tubes like clock shades (fig. 3), the photographic proof, obtained after forty-eight hours, showed silhouettes of the plates of glass (fig. 4), just as if they had been produced by the total refraction and reflection of rays identical with those of light, but which must have traversed the 2 mm. of aluminum. This photograph is unique: I have never been able to reproduce it or obtain any action with the same sample of sulphide of calcium, nor with any other phosphorescent preparation. At about the same time M. Niewenglowski obtained an impression with sulphide of calcium, and M. Troost with hexagonal blende. To this day I do not know the cause of the activity of these products or its disappearance. These facts, and some others, gave me the idea that the new rays might be a transversal movement of the ether analogous to that of light; but the absence of refraction and a large number of other experiments made me abandon this hypothesis.

In this same year, 1896, I found that all the uranium salts emitted rays of a similar nature, that the radiant property is an atomic one belonging to the element uranium, and electric measurements showed me that metallic uranium was about three and a half times more active in ionizing air than is the double sulphate of uranium and potassium. The same method enables us to study the rôle played by the gases in the discharge, and to observe that a sphere of electrified uranium retains its charge in vacuo, while in air it loses it. The rate of the fall of potential is sensibly proportional to the potential if the latter is

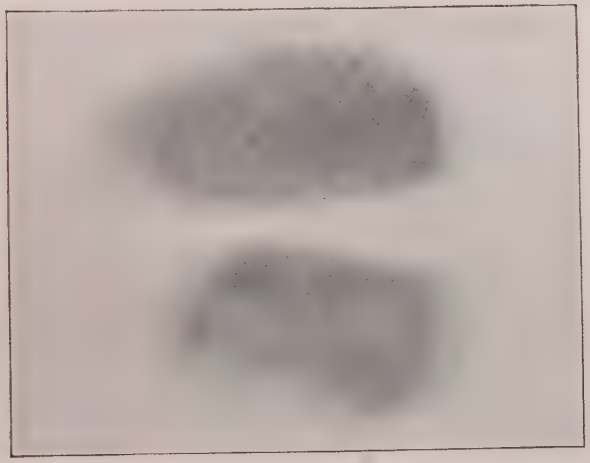


FIG. 1.—REPRODUCTION OF A THIN STRIP OF COPPER, IN FORM OF A CROSS, BY RAYS OF URANIUM ON A PHOTOGRAPHIC PLATE WRAPPED IN BLACK PAPER.

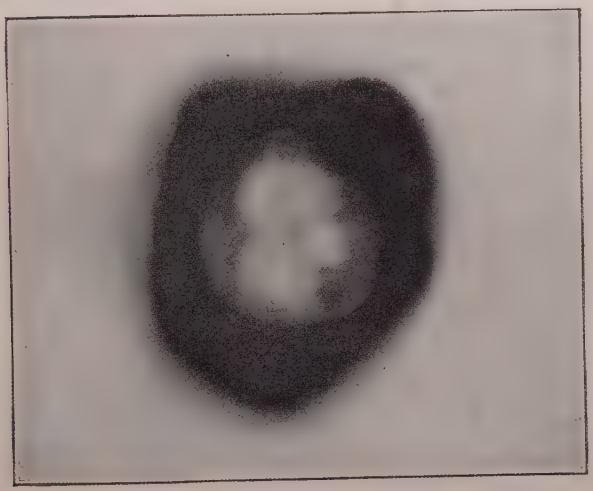


FIG. 2.—RADIOGRAPH OF ALUMINUM MEDAL PRODUCED BY RAYS OF URANIUM.

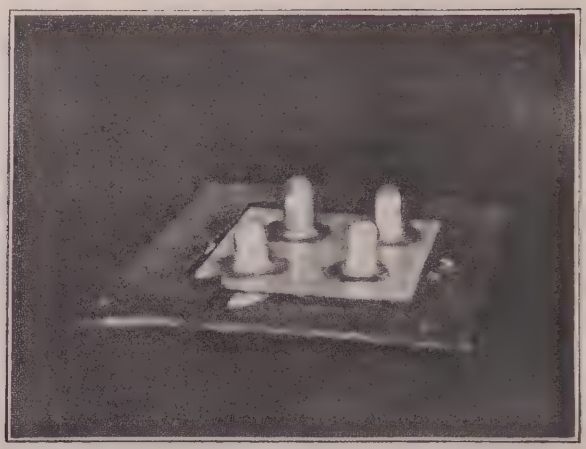


FIG. 3.—EXPERIMENTS WITH PHOSPHORESCENT POWDERS.



FIG. 4.—SILHOUETTES OF SHEETS OF GLASS OBTAINED BY RAYS OF PHOSPHORESCENT SUBSTANCES.

only a few volts; it should be constant and independent of the potential when this is very high. Gas rendered conducting by these rays retains this property for some instants. Between two conductors maintained at constant potentials these rays set up in air a continuous current.

These experiments were taken up and elaborated by Lord Kelvin in 1897, then by Messrs. Beattie and S. de Smolan. In 1899 Mr. Rutherford showed how the phenomena due to the conductivity communicated to gases by uranium, and the existence of a maximum in the current produced, could be explained by the hypothesis of ionization, to which the beautiful work of Mr. J. J. Thomson has given the seal of authority.

In 1898 M. Schmidt and Mme. Curie observed, quite independently, that thorium has properties analogous to those of uranium, properties which were specially examined by Mr. Owens and Mr. Rutherford. Mme. Curie having measured the ionizing activity of a large number of minerals containing uranium or thorium, announced the remarkable fact that several minerals were more active than metallic uranium. M. and Mme. Curie concluded that there must be a more active body than uranium in the mineral, and they undertook the task of isolating it.

By treating one of the most active of these minerals, viz, pitchblende from Joachimstal, they first separated an active bismuth, to which they gave the name of polonium, then shortly afterward they obtained a very active barium containing a new element, radium.

These bodies are prepared by fractional precipitations, in which one is guided by the indications of the electrometer; the activity of these products is 100,000 times greater than that of uranium.

About the same time M. Giesel succeeded in preparing some very active substances, and in 1900 M. Debierne announced the existence of a new element, actinium, about which, however, we have not heard many particulars. Of all these new bodies radium alone is characterized as a new element; it has an emission spectrum consisting of lines which do not belong to any other known body, and the atomic weight of the active salts of barium was found to increase with the proportion of radium present.

The activity of uranium was not sufficient to excite phosphorescence in other bodies; M. and Mme. Curie, however, observed this phenomenon with the rays from radium, and further, that the salts of radium were themselves luminous, their luminosity being, like their radioactivity, spontaneous. The activity of radium produces various chemical reactions; it colors glass, it transforms oxygen into ozone, it changes white phosphorus to red, it ionizes not only gases but also liquids, such as petroleum and liquid air, and insulating solid bodies, such as paraffin, developing in this latter body a residual conductivity which lasts a long time after the rays have ceased to act. It also causes on organic tissues serious burns analogous to those produced by X-rays.

The sample of radium that M. and Mme. Curie have lent me for the purpose of this lecture enables me to show you a few of these phenomena—ionization of the air, luminosity, and phosphorescence.

I have observed by means of the photograph I now show (fig. 5), that the radio-activity of polonium will not traverse a thin sheet of black paper forming a small cylinder closed by aluminium or mica, and at the bottom of which was placed the powdered material. The rays from radium easily pass through this envelope. We shall see that still more profound differences exist between these two kinds of rays.

The radio-activity of radium restores to certain crystals and to glass the property of becoming phosporescent by heat, which they have lost owing to a previous elevation of temperature.

The phenomena of absorption, examined either by means of photography, by phosphorescence, or by ionization of the air, showed the heterogeneity of the class of radiations emitted. Subsequent observations have enlarged the field of this research.

Toward the end of the year 1899 M. Giesel, and then MM. Meyer and Schweidler, observed that the rays of radio-active preparations were deviated by a magnetic field in the same manner as are the cathodic rays. For my part, at about the same time, without having heard of these experiments, I observed the same phenomenon with radium. The experiment can be made in the following manner: A small paper box containing a few grains of the radio-active body is placed horizontally on a photographic plate covered with black paper, between the poles of a magnet; the rays are thrown entirely to one side of the plate. I here show my two first photographs, one of which shows a concentration on one pole of the magnet.

Very shortly afterwards I observed that the rays from polonium are not deviated, and consequently that two kinds of rays exist, one deviable and the other nondeviable. M. and Mme. Curie have made an electric examination of this subject, which has proved the simultaneous existence of these two kinds of rays in the radio-activity of radium, their unequal permeability varying with the distance from the absorbing screens. The accompanying photograph (fig. 6) shows these two kinds of rays from radium. I have recently observed that uranium emits only deviable rays—that is, saving the existence of much less active, nondeviable rays. In fact, there does exist a third kind of rays which are not deviable, but are extremely penetrating; they have been shown more particularly by M. Villard.

Thus the activity of radio-active bodies comprises three kinds of rays—rays which are deviable in a magnetic field, which appear to be identical with cathodic rays, and two sorts of nondeviable rays, one kind being very easily absorbed, the other resembling X-rays and

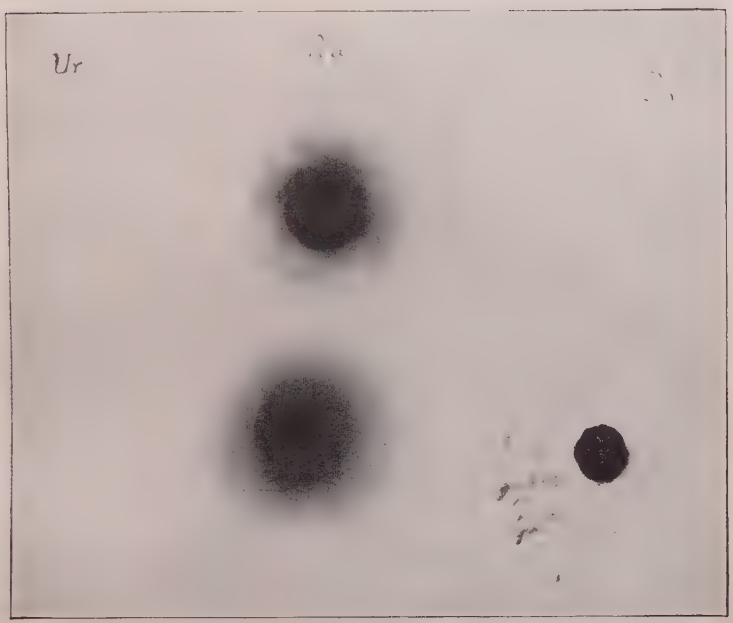


FIG. 5.—COMPARISON OF RAYS OF URANIUM, RADIUM, AND POLONIUM.

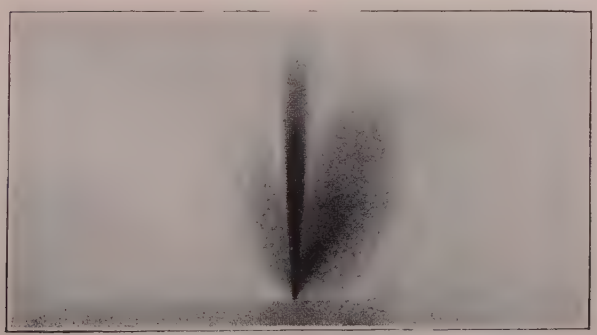


FIG. 6.—DEVIABLE AND NONDEVIABLE RAYS OF RADIUM.



FIG. 7.—THEORETICAL ARCS FORMED IN AIR AND IN VACUO BY DEVIABLE RAYS.

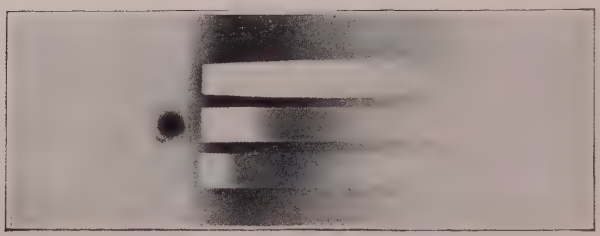


FIG. 8.—DISPERSION OF DEVIABLE RAYS IN MAGNETIC FIELD.

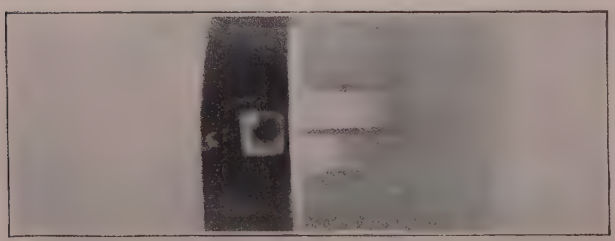


FIG. 9.—IMPRESSION DUE TO SECONDARY RAYS.

being very penetrating. Uranium emits principally the first kind, polonium gives only the second, and radium gives all three at once.[a]

Let us now return to deviable rays; the material theory of Sir William Crookes and Mr. J. J. Thomson can be applied to them, and the consequences can be verified with the greatest facility. In a uniform magnetic field the trajectories perpendicular to the field are circumferential to the path ρ which leads the rays to the point of emission. For an oblique emission making an angle with the field, the trajectories are helices enveloping the cylinders with rays $\rho \sin \alpha$. By placing on a horizontal photographic plate parallel to the uniform field, a small lead box containing a few grains of radiferous barium forming a source of very small diameter, the rays are drawn down to the plate, and excite it on one side alone; a bundle of simple rays emitted in the plane normal to the plate and parallel to the field should show theoretically an arc of an ellipse of which the axes are in the proportion of 2 and π. The accompanying photograph (fig. 7) shows these theoretical arcs, obtained by reversing the direction of the field, the one in air and the other in vacuo, on a photographic plate enveloped in black paper; the intensity of the magnetic field was about 4,000 C. G. S. units.

If we do not inclose the photographic plate, and if we arrange on it several strips of paper or of metal to form screens, we observe in the print of the radio-activity dispersed by the magnetic field, a species of absorption spectra. Each trajectory has a different curvature corresponding to rays of different speeds and having different penetrating powers.

Here is an example of one of these prints, obtained in a field of about 1,740 C. G. S. units; the screens are a strip of black paper, a strip of aluminum of 0.1 mm. thickness, and a strip of platinum of 0.03 mm. thickness (fig. 8). To obtain a pure spectrum so that at each point of the plate a bundle of rays are found, of which the trajectories have all the same curvature, the rays should be made to issue from the source so as to pass through a small round opening; the result is the same as the preceding one (fig. 9). This latter also shows a very intense impression, due to the secondary rays, provoked by the rays which were stopped by the lead cover over the active body, and in which was made a small opening through which the pure spectrum passed. The absorption varies with the distance of the screen from the active body, and the rays which are stopped by a screen placed on

[a] Récemment, Mr. Rutherford a reconnu par la méthode électrique que les rayons tous absorbables, qu'il a appelés rayons α, étaient faiblement déviés en sens contraire des rayons cathodiques, et assimilables aux Kanalstrahlen. J'ai pu, de mon côté, mesurer cette déviation par la méthode photographique, et montrer que les rayons de polonium sont identiques aux rayons α du radium. (Note by Professor Becquerel March 11, 1903.)

the plate are able to traverse this same screen when it is interposed at a point near their source.

These experiments leave no doubt as to the identity of the deviable rays with cathodic rays. However, it was necessary to prove that they carry charges of negative electricity, and that they are deviated by an electric field.

M. and Mme. Curie, in a beautiful experiment, have shown that the rays of radium charge negatively the bodies that receive them, and that the source becomes charged positively. For this double experiment it is necessary that all the conductors and the source itself be completely enveloped in an insulating material, such as paraffin. For the active body examined the charge was 4.10^{-13} C. G. S. units per square centimeter of radiating surface per second.

For my part, I have shown and measured the electrostatic deviation by projecting the deviated shadow of a screen placed perpendicular to the field, on a photographic plate. One of these apparatus is here shown (fig. 10), as well as one of the prints obtained (fig. 11), in which on the two halves of the same plate appear the two deviated shadows corresponding to the reversal of the electric field, of which the intensity was $1.02 : 10^{12}$.

The ballistic hypothesis attributes these phenomena to material masses transporting charges of negative electricity with very great rapidity. Let m be the material mass of a particle, e its charge, and v its velocity. We know that in a magnetic field of an intensity H, the radius of curvature ρ of the circular trajectory is given by the equation $H\rho = \frac{m}{e} v$. The numerical value of the product $H\rho$ serves to show the character of each simple ray. On the other hand, in an electric field of an intensity F, the parameter of the parabolic trajectory is $\frac{m}{e}\frac{v^2}{F}$. The knowledge of these two values gives $\frac{m}{e}$ and v. With a value of $H\rho = 1{,}550$ I obtained approximately $v = 2.21 \times 10^{10}$, and $\frac{e}{m} = 1.42 \times 10^{7}$. These figures are entirely of the same order in value as those which led to the measurements made with cathodic rays, and the theoretical considerations with regard to Zeeman's experiment.

From the above figures we deduce that, from the fact of the deviable radio-activity under consideration, there escapes from each square centimeter of radio-active surface 1.2 milligrams of matter in a thousand million years.

By extending these measurements to radiations of different and well-known natures, we ought to be able to determine if the relation $\frac{e}{m}$ is constant, or variable with one ray or another, and whether these do not differ only in their speeds; I have not yet finished the experiments I undertook to decide this fundamental question, but recently M.

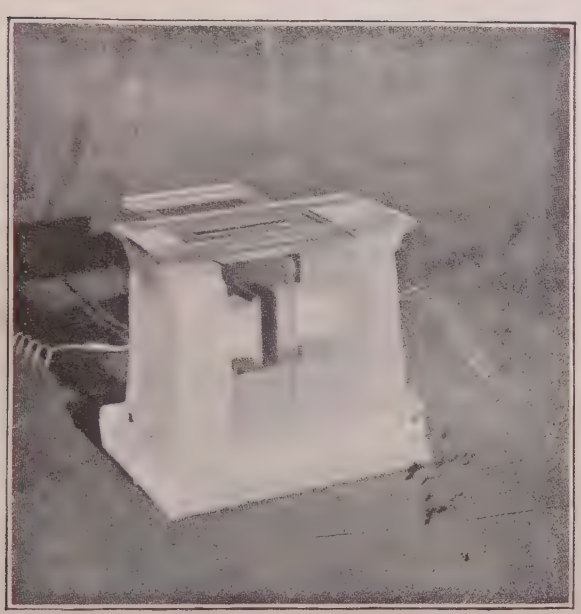


FIG. 10.—APPARATUS FOR PROJECTING ON A PHOTOGRAPHIC PLATE THE SHADOW OF A SCREEN PERPENDICULAR TO THE MAGNETIC FIELD.

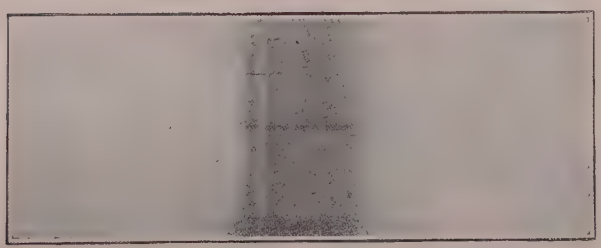


FIG. 11.—PROOF OBTAINED WITH APPARATUS IN FIG. 10.



FIG. 12.—ARRANGEMENT EMPLOYED TO SHOW THE DISCONTINUITY OF DEVIABLE AND NONDEVIABLE RAYS.



FIG. 13.—FIRST PICTURE OBTAINED BY THE ARRANGEMENT SHOWN IN FIG. 12.

Kaufmann has attempted to elucidate the matter. He combined, at right angles, the magnetic and the electric actions; unfortunately, the experiment, which is very difficult to perform, did not give him one plate fit to measure. For the values of $H\rho$ comprised between 1,800 and 4,600, he found that the relation $\frac{e}{m}$ varied from $1.3 : 10^7$, to $0.6 : 10^7$, and the speed v from $2.3 : 10^{10}$ to $2.8 : 10^{10}$.

The proof of a regular variation in the calculated relation $\frac{e}{m}$ is of considerable theoretical importance; if this relation was constant, as it seemed to be as the result of a large number of measurements, we might conclude that the slightly deviable rays, for which $H\rho$ is more than 5,000, have speeds considerably greater than that of light.

On the other hand, theoretical considerations have given the idea that the speed could not surpass that of the propagation of electro-magnetic disturbances—that is to say, the speed of light—and we have been led to consider the mobile masses in a magnetic field as endowed with a particular inertia, which is a function of the speed. Under these conditions the calculated mass ought to be apparent, or at least partly so, and it should increase indefinitely as the actual speed approaches that of light. The figures published by M. Kaufmann bear out this hypothesis.

Another consequence of this manner of looking at the question would be that there should be continuity between the deviable rays and those which are not, as the radius of curvature of the trajectories becomes infinite at the same time as the apparent mass.

The photographic print already mentioned (fig. 6), as well as one of the following ones (fig. 13), showed, on the contrary, a very distinct discontinuity, although in the second one the exposure was sufficiently prolonged for the impression of the least active rays, such as the penetrating nondeviable ones, to be distinctly visible.

This proof was obtained in the following manner: In the uniform magnetic field of a permanent magnet I placed, normally to the field, a photographic plate; then on this latter I arranged screens of lead fixed on a sheet of glass, as shown in fig. 12. These screens are pierced with openings normal to the plate, and destined to limit the width of the beam; in the path of these beams I arranged other screens, such as aluminium ones. Below the plate opposite a narrow slit in a strip of lead a small block of lead is placed having a deep cavity normal to the plate, and in which the radiant body is placed. We have thus a narrow linear source normal to the plate and several millimeters in length. The cavity is covered with a thin sheet of aluminium to stop the light rays.

The figure represents a section made normally to the field of the beam, of which a part is deviated. Each beam corresponding to a determined speed gives an impression which is noticeably curved, as if

the entire trajectory was marked on the plate. In these photographs the interior of the cylinders forming the screens is strongly affected by the secondary emission from the lead. The first picture (fig. 13) shows that through each opening there passes an infinity of rays, constituting portions of the pure spectra. These meet with a strip of aluminium 0.1 mm. in thickness, and traverse it without deviation, but not all with equal facility. The slightly deviated rays are penetrating, and excite secondary radiations when leaving the aluminium. The very deviable rays are stopped and give rise to points affected by an intense secondary radiation.

One only of the two categories of nondeviable rays appears in the form of two fine lines opposite the source; these are very penetrating rays, the others were arrested quite near the source.

Another picture (fig. 14) shows the simple beam obtained by a double series of openings; by one of them we can sometimes pass two distinct trajectories.

The third figure is of interest, as it shows the straight beam traversing, without deviation, a sheet of aluminium placed obliquely to the line of trajectory; and, finally, the fourth one shows the transmission of simple rays through aluminium, and the secondary effects they produce.

The same method has enabled me to observe that the secondary rays were themselves deviated by the magnetic field in the same way as the exciting rays.

The radiations from radium also comprise some which are very penetrating, consisting of the least deviable and the nondeviable rays, of which the properties seem to be the same as Röntgen rays. These penetrating rays are but very slightly absorbed, and consequently their action on a photographic plate or on the air is very feeble, so that by the preceding methods we can get no very exact idea of their intensity. If we interpose in their path a very absorbent screen, they traverse it partially, but at the same time they become partially transformed into more absorbable rays. This transformation recalls that of fluorescence, and, through the secondary action, the effect immediately behind the screen is stronger than if this latter was not there. The photographic plate receiving the radiations—filtered through a thickness of lead of 1 cm.—gives a stronger impression through a sheet of lead of 1 mm. thickness than in the uncovered regions. The diagram (fig. 15) shows the effect of the radiations coming from the sides of a leaden box after having traversed 5 to 12 mm. of the metal.

These secondary phenomena may partially account for the appearance of shadows given by the edges of all the transparent screens placed over the photographic plates.

All the facts I have just related have exclusively to do with the obscure radiations which traverse opaque bodies, such as metal, glass, mica, etc. But there exists also another, quite different, phenomenon, of which the effects are arrested by glass and mica; they are compar-

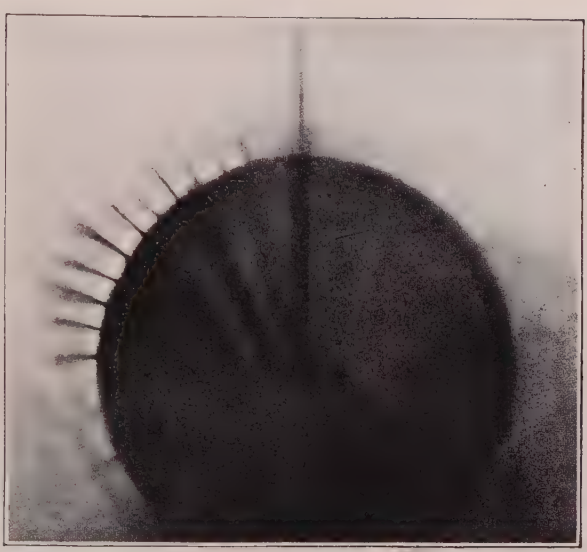


FIG. 14.—SECOND PICTURE OBTAINED BY THE ARRANGEMENT SHOWN IN FIG. 12.

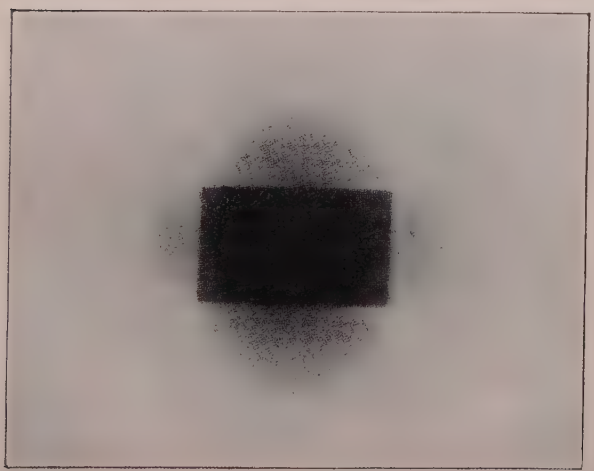


FIG. 15.—EFFECT OF RADIATIONS FROM SIDES OF LEADEN BOX AFTER TRAVERSING 5 TO 12 MM. OF THE METAL.

able to those produced by a vapor of a special nature. This phenomenon was discovered in 1899 by Mr. Rutherford and by M. and Mme. Curie simultaneously.

Mr. Rutherford, while examining the radiations from thorium, observed that, besides the ordinary rays, there was another effect produced by an "emanation" consisting of a sort of vapor ionizing the air. This vapor is deposited on bodies, principally those electrified negatively, and makes them momentarily radio-active. Mr. Rutherford made some very interesting measurements of this phenomenon.

At the same time, M. and Mme. Curie discovered that, under the influence of radium, bodies became temporarily radio-active. This is not the secondary effect already described, but a persistent phenomenon which disappears comparatively slowly from the moment when the action of the radium ceases. M. Curie has called this "induced radio-activity," and has made a very complete examination of it. He has observed that the phenomenon is produced with great intensity in a close space, that induced activity is the same on all bodies and practically independent of the pressure inside the inclosed space, but that the phenomenon is not produced if we maintain a complete vacuum by removing the gases produced; solutions of salts of radium produce the same effect with greater intensity than the solid salts. Liquids, water of crystallization extracted from active salts, or the water separated from an active solution by a semipermeable membrane of celluloid, remain strongly radio-active; it is the same with the gases. These excited bodies produce the same effects as radium; they emit a penetrating ray which traverses the glass vessels which contain them and makes these latter luminous. Induced activity is gradually propagated in gases in a sealed tube, even through capillary tubes and imperceptible cracks; bodies are excited the more as the volume of gas is greater in proportion to their surface. Phosphorescent bodies become luminous when excited. In a recent work MM. Elster and Geitel have observed that atmospheric air has properties analogous to those of excited gases, and M. Geitel has been able to collect on wires, negatively electrified, traces of radio-active products. The cause of this radio-activity is a problem of the greatest interest.

Finally, there is a remarkable method of induction, which is of such a nature as to demand the greatest reserve in the conclusions which might be formulated relative to the presence of new elements in radio-active bodies. Every inactive substance which has been added to a solution of a uranium or radium salt, and which has subsequently been removed by precipitation, has become radio-active, and loses this radio-activity very slowly. This fact was first observed by M. Curie and M. Giesel, who rendered bismuth radio-active in this manner. In the case of uranium, a trace of barium, precipitated in the form of sulphate, became notably more active than the uranium; barium thus excited emits only deviable rays like uranium.

After this precipitation the uranium salt brought back to the solid state is less radio-active than before; this loss of radio-activity can even be accentuated by successive operations, but the products gradually and spontaneously regain their original activity. The temporary diminution of activity after solution is a general fact for salts of uranium and radium. With salts of actinium M. Debierne has communicated a very great activity to barium. The barium thus excited can be separated from inactive barium; it can be fractioned like radiferous chloride of barium, the most active portions being the least soluble in water and hydrochloric acid. M. Debierne in this manner obtained a product a thousand times more active than uranium. Barium thus excited behaves as a false radium, but it differs from the true radium in the absence of the spectrum and in gradually losing its power with time.

Among the radio-active preparations a large number may be temporarily excited bodies. Such is the case with "polonium," which is apparently only excited bismuth.

Uranium and radium are characterized by their emission spectra and by the stability of their radio-activity. The spontaneous growth that is observed in the salts deposited by the solutions[a] might find an explanation in a phenomenon of auto-induction of the active molecules on the inactive one they are associated with.

The origin of the radiant energy of these radio-active bodies is still an enigma. By the material hypothesis it does not appear unreasonable, by applying the phenomenon of the evaporation of an odoriferous body to compare the emanation to a sort of gas of which the molecules would have masses of the same order of size as electrolytic ions, and to identify the radiations with the cathodic rays resulting from the dislocation of these ions and causing at the same time the emission of X-rays. We might thus ascribe the expenditure of energy to the dissipation of active matter. Although this hypothesis will account for most of the known facts, still there does not exist any precise experiment which sanctions it.

I must not, however, dwell longer on this subject, of which I have incompletely summarized the present position, by emphasizing the physical part, which comes more especially within my province, although the chemical side has given rise to work of the greatest interest.

These questions have raised new hopes on the transformation of matter. Besides the exceptional conditions under which they enable us to examine the cathodic rays, they have raised, and continue to raise, fresh problems every day of which the first and most mysterious is the spontaneity of the radiations.

[a] "L'accroissement spontané que l'on observe sur les sels déposés des dissolutions."

HISTORY OF COLD AND THE ABSOLUTE ZERO.[a]

By Prof. James Dewar, M. A., LL.D., D. Sc., F. R. S.

It was Tyndall's good fortune to appear before you at a moment when a fruitful and comprehensive idea was vivifying the whole domain of scientific thought. At the present time no such broad generalization presents itself for discussion, while, on the other hand, the number of specialized studies has enormously increased. Science is advancing in so broad a front by the efforts of so great an army of workers that it would be idle to attempt, within the limits of an address to the most indulgent of audiences, anything like a survey of chemistry alone. But I have thought it might be instructive, and perhaps not uninteresting, to trace briefly in broad outline the development of that branch of study with which my own labors have been recently more intimately connected—a study which I trust I am not too partial in thinking is as full of philosophical interest as of experimental difficulty. The nature of heat and cold must have engaged thinking men from the very earliest dawn of speculation upon the external world; but it will suffice for the present purpose if, disregarding ancient philosophers and even medieval alchemists, we take up the subject where it stood after the great revival of learning, and as it was regarded by the father of the inductive method. That this was an especially attractive subject to Bacon is evident from the frequency with which he recurs to it in his different works, always with lamentation over the inadequacy of the means at disposal for obtaining a considerable degree of cold. Thus, in the chapter in the Natural History, "Sylva Sylvarum," entitled "Experiments in consort touching the production of cold," he says, "The production of cold is a thing very worthy of the inquisition both for the use and the disclosure of causes. For heat and cold are nature's two hands whereby she chiefly worketh, and heat we have in readiness in respect of the fire, but for cold we must stay till it cometh or seek

[a] Presidential address before British Association for the Advancement of Science, at Belfast meeting, 1902, reprinted, after revision by the author, from pamphlet copy of the address. The introductory part of the address, relating to other topics, is omitted.

it in deep caves or high mountains, and when all is done we can not obtain it in any great degree, for furnaces of fire are far hotter than a summer sun, but vaults and hills are not much colder than a winter's frost." The great Robert Boyle was the first experimentalist who followed up Bacon's suggestions. In 1682 Boyle read a paper to the Royal Society on "New experiments and observations touching cold, or an experimental history of cold," published two years later in a separate work. This is really a most complete history of everything known about cold up to that date, but its great merit is the inclusion of numerous experiments made by Boyle himself on frigorific mixtures and the general effects of such upon matter. The agency chiefly used by Boyle in the conduct of his experiments was the glaciating mixture of snow or ice and salt. In the course of his experiments he made many important observations. Thus he observed that the salts which did not help the snow or ice to dissolve faster gave no effective freezing. He showed that water in becoming ice expands by about one-ninth of its volume, and bursts gun barrels. He attempted to counteract the expansion and prevent freezing by completely filling a strong iron ball with water before cooling, anticipating that it might burst the bottle by the stupendous force of expansion, or that if it did not, then the ice produced might under the circumstances be heavier than water. He speculated in an ingenious way on the change of water into ice. Thus he says, "If cold be but a privation of heat through the recess of that ethereal substance which agitated the little eel-like particles of the water and thereby made them compose a fluid body, it may easily be conceived that they should remain rigid in the postures in which the ethereal substance quitted them, and thereby compose an unfluid body like ice; yet how these little eels should by that recess acquire as strong an endeavor outward as if they were so many little springs and expand themselves with so stupendous a force, is that which does not so readily appear." The greatest degree of adventitious cold Boyle was able to produce did not make air exposed to its action lose a full tenth of its own volume, so that, in his own words, the cold does not "weaken the spring by anything near so considerable as one would expect." After making this remarkable observation and commenting upon its unexpected nature, it is strange Boyle did not follow it up. He questions the existence of a body of its own nature supremely cold, by participating in which all other bodies obtain that quality, although the doctrine of a primum frigidum had been accepted by many sects of philosophers; for, as he says, "if a body being cold signify no more than its not having its sensible parts so much agitated as those of our sensorium, it suffices that the sun or the fire or some other agent, whatever it were, that agitated more vehemently its parts before, does either now cease to agitate them or agitates them but very remissly, so that till it be determined whether

cold be a positive quality or but a privative it will be needless to contend what particular body ought to be esteemed the primum frigidum." The whole elaborate investigation cost Boyle immense labor, and he confesses that he "never handled any part of natural philosophy that was so troublesome and full of hardships." He looked upon his results but as a "beginning" in this field of inquiry, and for all the trouble and patience expended he consoled himself with the thought of "men being oftentimes obliged to suffer as much wet and cold and dive as deep to fetch up sponges as to fetch up pearls." After the masterly essay of Boyle the attention of investigators was chiefly directed to improving thermometrical instruments. The old air thermometer of Galileo being inconvenient to use, the introduction of fluid thermometers greatly aided the inquiry into the action of heat and cold. For a time great difficulty was encountered in selecting proper fixed points on the scales of such instruments, and this stimulated men like Huygens, Newton, Hooke, and Amontons to suggest remedies and to conduct experiments. By the beginning of the eighteenth century the freezing point and the boiling point of water were agreed upon as fixed points, and the only apparent difficulties to be overcome were the selection of the fluid, accurate calibration of the capillary tube of the thermometer, and a general understanding as to scale divisions. It must be confessed that great confusion and inaccuracy in temperature observations arose from the variety and crudeness of the instruments. This led Amontons in 1702–3 to contribute two papers to the French Academy which reveal great originality in the handling of the subject, and which, strange to say, are not generally known. The first discourse deals with some new properties of the air and the means of accurately ascertaining the temperature in any climate. He regarded heat as due to a movement of the particles of bodies, though he did not in any way specify the nature of the motion involved, and as the general cause of all terrestrial motion, so that in its absence the earth would be without movement in its smallest parts. The new facts he records are observations on the spring or pressure of air brought about by the action of heat. He shows that different masses of air measured at the same initial spring or pressure, when heated to the boiling point of water, acquire equal increments of spring or pressure, provided the volume of the gas be kept at its initial value. Further, he proves that if the pressure of the gas before heating be doubled or tripled, then the additional spring or pressure resulting from heating to the boiling point of water is equally doubled or tripled. In other words, the ratio of the total spring of air at two definite and steady temperatures and at constant volume is a constant, independent of the mass or the initial pressure of the air in the thermometer. These results led to the

increased perfection of the air thermometer as a standard instrument, Amontons's idea being to express the temperature at any locality in fractions of the degree of heat of boiling water. The great novelty of the instrument is that temperature is defined by the measurement of the length of a column of mercury. In passing, he remarks that we do not know the extreme of heat and cold, but that he has given the results of experiments which establish correspondences for those who wish to consider the subject. In the following year Amontons contributed to the Academy a further paper extending the scope of the inquiry. He there pointed out more explicitly that as the degrees of heat in his thermometer are registered by the height of a column of mercury, which the heat is able to sustain by the spring of the air, it follows that the extreme cold of the thermometer will be that which reduces the air to have no power of spring. This, he says, will be a much greater cold than what we call "very cold," because experiments have shown that if the spring of the air at boiling point is 73 inches, the degree of heat which remains in the air when brought to the freezing point of water is still very great, for it can still maintain the spring of 51½ inches. The greatest climatic cold on the scale of units adopted by Amontons is marked 50, and the greatest summer heat 58, the value for boiling water being 73, and the zero being 52 units below the freezing point. Thus Amontons was the first to recognize that the use of air as a thermometric substance led to the inference of the existence of a zero of temperature, and his scale is nothing else than the absolute one we are now so familiar with. It results from Amontons's experiments that the air would have no spring left if it were cooled below the freezing point of water to about two and one-half times the temperature range which separates the boiling point and the freezing point. In other words, if we adopt the usual centessimal difference between these two points of temperature as 100°, then the zero of Amontons's air thermometer is minus 240°. This is a remarkable approximation to our modern value for the same point of minus 273°. It has to be confessed that Amontons's valuable contributions to knowledge met with that fate which has so often for a time overtaken the work of too-advanced discoverers; in other words, it was simply ignored, or in any case not appreciated by the scientific world either of that time or half a century later. It was not till Lambert, in his work on Pyrometrie, published in 1779, repeated Amontons's experiments and indorsed his results, that we find any further reference to the absolute scale or the zero of temperature. Lambert's observations were made with the greatest care and refinement, and resulted in correcting the value of the zero of the air scale to minus 270°, as compared with Amontons's minus 240°. Lambert points out that the degree of temperature which is equal to zero is what one may call absolute cold, and that at this temperature the volume of the air would be practically nothing. In other words, the particles of the air would fall together

and touch each other and become dense like water, and from this it may be inferred that the gaseous condition is caused by heat. Lambert says that Amontons' discoveries had found few adherents, because they were too beautiful and advanced for the time in which he lived.

About this time a remarkable observation was made by Professor Braun at Moscow, who, during the severe winter of 1759, succeeded in freezing mercury by the use of a mixture of snow and nitric acid. When we remember that mercury was regarded as quite a peculiar substance possessed of the essential quality of fluidity, we can easily understand the universal interest created by the experiment of Braun. This was accentuated by the observations he made on the temperature given by the mercury thermometer, which appeared to record a temperature as low as minus 200° C. The experiments were soon repeated by Hutchins at Hudson Bay, who conducted his work with the aid of suggestions given him by Cavendish and Black. The result of the new observations was to show that the freezing point of mercury is only minus 40° C., the errors in former experiments having been due to the great contraction of the mercury in the thermometer in passing into the solid state. From this it followed that the enormous natural and artificial colds which had generally been believed in had no proved existence. Still the possible existence of a zero of temperature very different from that deduced from gas thermometry had the support of such distinguished names as those of Laplace and Lavoisier. In their great memoir on Heat, after making what they consider reasonable hypotheses as to the relation between specific heat and total heat, they calculate values for the zero which range from 1,500° to 3,000° below melting ice. On the whole, they regard the absolute zero as being in any case 600° below the freezing point. Lavoisier, in his Elements of Chemistry, published in 1792, goes further in the direction of indefinitely lowering the zero of temperature when he says:

"We are still very far from being able to produce the degree of absolute cold, or total deprivation of heat, being unacquainted with any degree of coldness which we can not suppose capable of still further augmentation; hence it follows we are incapable of causing the ultimate particles of bodies to approach each other as near as possible, and thus these particles do not touch each other in any state hitherto known."

Even as late as the beginning of the nineteenth century we find Dalton, in his new system of Chemical Philosophy, giving ten calculations of this value, and adopting finally as the natural zero of temperature minus 3,000° C.

In Black's lectures we find that he takes a very cautious view with regard to the zero of temperature, but as usual is admirably clear with regard to its exposition. Thus he says:

"We are ignorant of the lowest possible degree or beginning of heat. Some ingenious attempts have been made to estimate what it

may be, but they have not proved satisfactory. Our knowledge of the degrees of heat may be compared to what we should have of a chain, the two ends of which were hidden from us and the middle only exposed to our view. We might put distinct marks on some of the links, and number the rest according as they are nearest to or further removed from the principal links; but not knowing the distance of any links from the end of the chain we could not compare them together with respect to their distance, or say that one link was twice as far from the end of the chain as another."

It is interesting to observe, however, that Black was evidently well acquainted with the work of Amontons and strongly supports his inference as to the nature of air. Thus, in discussing the general cause of vaporization, Black says that some philosophers have adopted the view "that every palpable elastic fluid in nature is produced and preserved in this form by the action of heat. Mr. Amontons, an ingenious member of the late Royal Academy of Sciences, at Paris, was the first who proposed this idea with respect to the atmosphere. He supposed that it might be deprived of the whole of its elasticity and condensed and even frozen into a solid matter were it in our power to apply to it a sufficient cold; that it is a substance that differs from others by being incomparably more volatile, and which is therefore converted into vapor and preserved in that form by a weaker heat than any that ever happened or can obtain in this globe, and which therefore can not appear under any other form than the one it now wears so long as the constitution of the world remains the same as at present." The views that Black attributes to Amontons have been generally associated with the name of Lavoisier, who practically admitted similar possibilities as to the nature of air; but it is not likely that in such matters Black would commit any mistake as to the real author of a particular idea, especially in his own department of knowledge. Black's own special contribution to low-temperature studies was his explanation of the interaction of mixtures of ice with salts and acids by applying the doctrine of the latent heat of fluidity of ice to account for the frigorific effect. In a similar way Black explained the origin of the cold produced in Cullen's remarkable experiment of the evaporation of ether under the receiver of an air pump by pointing out that the latent heat of vaporization in this case necessitated such a result. Thus, by applying his own discoveries to latent heat, Black gave an intelligent explanation of the cause of all the low-temperature phenomena known in his day.

After the gaseous laws had been definitely formulated by Gay-Lussac and Dalton, the question of the absolute zero of temperature, as deduced from the properties of gases, was revived by Clement and Desormes. These distinguished investigators presented a paper on the subject to the French Academy in 1812, which, it appears, was rejected by that body. The authors subsequently elected to publish it

in 1819. Relying on what we know now to have been a faulty hypothesis, they deduced from observations on the heating of air rushing into a vacuum the temperature of minus 267° as that of the absolute zero. They further endeavored to show, by extending to lower temperatures the volume or the pressure coefficients of gases given by Gay-Lussac, that at the same temperature of minus 267° the gases would contract so as to possess no appreciable volume, or, alternatively, if the pressure was under consideration it would become so small as to be nonexistent. Although full reference is given to previous work bearing on the same subject, yet curiously enough no mention is made of the name of Amontons. It certainly gave remarkable support to Amontons's notion of the zero to find that simple gases like hydrogen and compound gases like ammonia, hydrochloric, carbonic, and sulphurous acids should all point to substantially the same value for this temperature. But the most curious fact about this research of Clement and Desormes is that Gay-Lussac was a bitter opponent of the validity of the inferences they drew either from his work or their own. The mode in which Gay-Lussac regarded the subject may be succinctly put as follows: A quick compression of air to one-fifth volume raises its temperature to 300°, and if this could be made much greater and instantaneous the temperature might rise to 1,000° or 2,000°. Conversely, if air under five atmospheres were suddenly dilated it would absorb as much heat as it had evolved during compression and its temperature would be lowered by 300°. Therefore if air were taken and compressed to 50 atmospheres or more, the cold produced by its sudden expansion would have no limit. In order to meet this position Clement and Desormes adopted the following reasoning: They pointed out that it had not been proved that Gay-Lussac was correct in his hypothesis, but that in any case it tacitly involves the assumption that a limited quantity of matter possesses an unlimited supply of heat. If this were the case, then heat would be unlike any other measurable thing or quality. It is, therefore, more consistent with the course of nature to suppose that the amount of heat in a body is like the quantity of elastic fluid filling a vessel, which, while definite in original amount, one may make less and less by getting nearer to a complete exhaustion. Further, to realize the absolute zero in the one case is just as impossible as to realize the absolute vacuum in the other; and as we do not doubt a zero of pressure, although it is unattainable, for the same reason we ought to accept the reality of the absolute zero. We know now that Gay-Lussac was wrong in supposing the increment of temperature arising from a given gaseous compression would produce a corresponding decrement from an identical expansion. After this time the zero of temperature was generally recognized as a fixed ideal point, but in order to show that it was hypothetical, a distinction was

drawn between the use of the expressions zero of absolute temperature and the absolute zero.

The whole question took an entirely new form when Lord Kelvin, in 1848, after the mechanical equivalent of heat had been determined by Joule, drew attention to the great principles underlying Carnot's work on the Motive Power of Heat, and applied them to an absolute method of temperature measurement which is completely independent of the properties of any particular substance. The principle was that for a difference of 1° on this scale between the temperatures of the source and refrigerator, a perfect engine should give the same amount of work in every part of the scale. Taking the same fixed points as for the Centigrade scale, and making 100 of the new degrees cover that range, it was found that the degrees not only within that range, but as far beyond as experimental data supplied the means of comparison, differed by only minute quantities from those of Regnault's air thermometer. The zero of the new scale had to be determined by the consideration that when the refrigerator was at the zero of temperature the perfect engine should give an amount of work equal to the full mechanical equivalent of the heat taken up. This led to a zero of 273° below the temperature of freezing water, substantially the same as that deduced from a study of the gaseous state. It was a great advance to demonstrate by the application of the laws of thermodynamics not only that the zero of temperature is a reality, but that it must be located at 273° below the freezing point of water. As no one has attempted to impugn the solid foundation of theory and experiment on which Lord Kelvin based his thermodynamic scale, the existence of a definite zero of temperature must be acknowledged as a fundamental scientific fact.

LIQUEFACTION OF GASES AND CONTINUITY OF STATE.

In these speculations, however, chemists were dealing theoretically with temperatures to which they could not make any but the most distant experimental approach. Cullen, the teacher of Black, had indeed shown how to lower temperature by the evaporation of volatile bodies, such as ether, by the aid of the air pump, and the later experiments of Leslie and Wollaston extended the same principle. Davy and Faraday made the most of the means at command in liquefying the more condensable gases, while at the same time Davy pointed out that they in turn might be utilized to procure greater cold by their rapid reconversion into the aeriform state. Still the chemist was sorely hampered by the want of some powerful and accessible agent for the production of temperatures much lower than had ever been attained. That want was supplied by Thilorier, who in 1835 produced liquid carbonic acid in large quantities, and further made the fortunate discovery that the liquid could be frozen into a snow by its own evaporation. Faraday was prompt to take advantage of this new and potent agent. Under

exhaustion he lowered its boiling point from minus 78° C. to minus 110° C., and by combining this low temperature with pressure all the gases were liquefied by the year 1844, with the exception of the three elementary gases hydrogen, nitrogen, and oxygen, and three compound gases—carbonic oxide, marsh gas, and nitric oxide. Andrews, some twenty-five years after the work of Faraday, attempted to induce change of state in the uncondensed gases by using much higher pressures than Faraday employed. Combining the temperature of a solid carbonic acid bath with pressures of 300 atmospheres, Andrews found that none of these gases exhibited any appearance of liquefaction in such high states of condensation; but so far as change of volume by high compression went, Andrews confirmed the earlier work of Natterer by showing that the gases become proportionately less compressible with growing pressure. While such investigations were proceeding, Regnault and Magnus had completed their refined investigations on the laws of Boyle and Gay-Lussac. A very important series of experiments was made by Joule and Kelvin "On the thermal effects of fluids in motion" about 1862, in which the thermometrical effects of passing gases under compression through porous plugs furnished important data for the study of the mutual action of the gas molecules. No one, however, had attempted to make a complete study of a liquefiable gas throughout wide ranges of temperature. This was accomplished by Andrews in 1869, and his Bakerian lecture "On the continuity of the gaseous and liquid states of matter" will always be regarded as an epoch-making investigation. During the course of this research Andrews observed that liquid carbonic acid raised to a temperature of 31° C. lost the sharp concave surface of demarcation between the liquid and the gas, the space being now occupied by a homogeneous fluid which exhibited, when the pressure was suddenly diminished or the temperature slightly lowered, a peculiar appearance of moving or flickering striæ, due to great local alterations of density. At temperatures above 31° C. the separation into two distinct kinds of matter could not be effected even when the pressure reached 400 atmospheres. This limiting temperature of the change of state from gas to liquid Andrews called the critical temperature. He showed that this temperature is constant, and differs with each substance, and that it is always associated with a definite pressure peculiar to each body. Thus the two constants, critical temperature and pressure, which have been of the greatest importance in subsequent investigations, came to be defined, and a complete experimental proof was given that "the gaseous and liquid states are only distinct stages of the same condition of matter and are capable of passing into one another by a process of continuous change."

In 1873 an essay "On the continuity of the gaseous and liquid state," full of new and suggestive ideas, was published by van der Waals, who, recognizing the value of Clausius's new conception of the virial in

dynamics, for a long-continued series of motions, either oscillatory or changing exceedingly slowly with time, applied it to the consideration of the molecular movements of the particles of the gaseous substance, and after much refined investigation, and the fullest experimental calculation available at the time, devised his well-known equation of continuity. Its paramount merit is that it is based entirely on a mechanical foundation, and is in no sense empiric; we may therefore look upon it as having a secure foundation in fact, but as being capable of extension and improvement. James Thomson, realizing that the straight-line breach of continuous curvature in the Andrews isothermals was untenable to the physical mind, propounded his emendation of the Andrews curves—namely, that they were continuous and of S form. We also owe to James Thomson the conception and execution of a three-dimensional model of Andrews's results, which has been of the greatest service in exhibiting the three variables by means of a specific surface afterwards greatly extended and developed by Prof. Willard Gibbs. The suggestive work of James Thomson undoubtedly was a valuable aid to van der Waals, for as soon as he reached the point where his equation had to show the continuity of the two states this was the first difficulty he had to encounter, and he succeeded in giving the explanation. He also gave a satisfactory reason for the existence of a minimum value of the product of volume and pressure in the Regnault isothermals. His isothermals, with James Thomson's completion of them, were now shown to be the results of the laws of dynamics. Van der Waals applied the new equation to the consideration of the coefficients of expansion with temperature and of pressure with temperature, showing that although they were nearly equal, nevertheless they were almost independent quantities. His investigation of the capillarity constant was masterly, and he added further to our knowledge of the magnitudes of the molecules of gases and of their mean free paths. Following up the experiments of Joule and Kelvin, he showed how their cooling coefficients could be deduced, and proved that they vanished at a temperature in each case which is a constant multiple of the specific critical temperature. The equation of continuity developed by van der Waals involved the use of three constants instead of one, as in the old law of Boyle and Charles, the latter being only utilized to express the relation of temperature, pressure, and volume, when the gas is far removed from its point of liquefaction. Of the two new constants one represents the molecular pressure arising from the attraction between the molecules, the other four times the volume of the molecules. Given these constants of a gas, van der Waals showed that his equation not only fitted into the general characters of the isothermals, but also gave the values of the critical temperature, the critical pressure, and the critical volume. In the case of carbonic acid the theoretical results were found to be in remarkable

agreement with the experimental values of Andrews. This gave chemists the means of ascertaining the critical constants, provided sufficiently accurate data derived from the study of a few properly distributed isothermals of the gaseous substance were available. Such important data came into the possession of chemists when Amagat published his valuable paper on "The isothermals of hydrogen, nitrogen, oxygen, ethylene, etc.," in the year 1880. It now became possible to calculate the critical data with comparative accuracy for the so-called permanent gases oxygen and nitrogen, and this was done by Sarrau in 1882. In the meantime a great impulse had been given to a further attack upon the so-called permanent gases by the suggestive experiments made by Pictet and Cailletet. The static liquefaction of oxygen was effected by Wroblewski in 1883, and thereby the theoretical conclusions derived from van der Waals's equation were substantially confirmed. The liquefaction of oxygen and air was achieved through the use of liquid ethylene as a cooling agent, which enabled a temperature of minus 140° to be maintained by its steady evaporation in vacuo. From this time liquid oxygen and air came to be regarded as the potential cooling agents for future research, commanding as they did a temperature of 200° below melting ice. The theoretical side of the question received at the hands of van der Waals a second contribution, which was even more important than his original essay, and that was his novel and ingenious development of what he calls "The theory of corresponding states." He defined the corresponding states of two substances as those in which the ratios of the temperature, pressure, and volume to the critical temperature, pressure, and volume, respectively, were the same for the two substances, and in corresponding states he showed that the three pairs of ratios all coincided. From this a series of remarkable propositions were developed, some new, some proving previous laws that were hitherto only empiric, and some completing and correcting faulty though approximate laws. As examples, he succeeded in calculating the boiling point of carbonic acid from observations on ether vapor, proved Kopp's law of molecular volumes, and showed that at corresponding temperatures the molecular latent heats of vaporization are proportional to the absolute critical temperature, and that under the same conditions the coefficients of liquid expansion are inversely proportional to the absolute critical temperature, and that the coefficients of liquid compressibility are inversely proportional to the critical pressure. All these propositions and deductions are in the main correct, though further experimental investigation has shown minor discrepancies requiring explanation. Various proposals have been made to supplement van der Waals's equation so as to bring it into line with experiments, some being entirely empiric, others theoretical. Clausius, Sarrau, Wroblewski, Batteli, and others attacked the question empirically, and in

the main preserved the co-volume (depending on the total volume of the molecules) unaltered while trying to modify the constant of molecular attraction. Their success depended entirely on the fact that, instead of limiting the number of constants to three, some of them have increased them to as many as ten. On the other hand, a series of very remarkable theoretical investigations has been made by van der Waals himself, by Kammerlingh Onnes, Korteweg, Jaeger, Boltzmann, Dieterici, and Reinganum, and others, all directed in the main toward an admitted variation in the value of the co-volume while preserving the molecular attraction constant. The theoretical deductions of Tait lead to the conclusion that a substance below its critical point ought to have two different equations of the van der Waals type, one referring to the liquid and the other to the gaseous phase. One important fact was soon elicited—namely, that the law of correspondence demanded only that the equation should contain not more than three constants for each body. The simplest extension is that made by Reinganum, in which he increased the pressure for a given mean kinetic energy of the particles inversely in the ratio of the diminution of free volume, due to the molecules possessing linear extension. Berthelot has shown how a "reduced" isothermal may be got by taking two other prominent points as units of measurement instead of the critical coordinates. The most suggestive advance in the improvement of the van der Waals equation has been made by a lady, Mme. Christine Meyer. The idea at the base of this new development may be understood from the following general statement: van der Waals brings the van der Waals surfaces for all substances into coincidence at the point where volume, pressure, and temperature are nothing, and then stretches or compresses all the surfaces parallel to the three axes of volume, pressure, and temperature until their critical points coincide. But on this plan the surfaces do not quite coincide, because the points where the three variables are respectively nothing are not corresponding points. Mme. Meyer's plan is to bring all the critical points first into coincidence, and then to compress or extend all the representative surfaces parallel to the three axes of volume, pressure, and temperature until the surfaces coincide. In this way, taking twenty-nine different substances, she completely verifies from experiment van der Waals's law of correspondence. The theory of van der Waals has been one of the greatest importance in directing experimental investigation and in attacking the difficult problems of the liquefaction of the most permanent gases. One of its greatest triumphs has been the proof that the critical constants and the boiling point of hydrogen theoretically deduced by Wroblewski from a study of the isothermals of the gas taken far above the temperature of liquefaction are remarkably near the experimental values. We may safely infer, therefore, that if hereafter a gas be discovered in small quantity even four times more volatile

than liquid hydrogen, yet by a study of its isothermals at low temperature we shall succeed in finding its most important liquid constants, although the isolation of the real liquid may for the time be impossible. It is perhaps not too much to say that as a prolific source of knowledge in the department dealing with the continuity of state in matter, it would be necessary to go back to Carnot's cycle to find a proposition of greater importance than the theory of van der Waals and his development of the law of corresponding states.

It will be apparent from what has just been said that, thanks to the labors of Andrews, van der Waals, and others, theory had again far outrun experiment. We could calculate the constants and predict some of the simple physical characteristics of liquid oxygen, hydrogen, or nitrogen with a high degree of confidence long before any one of the three had been obtained in the static liquid condition permitting of the experimental verification of the theory. This was the more tantalizing, because, with whatever confidence the chemist may anticipate the substantial corroboration of his theory, he also anticipates with almost equal conviction that as he approaches more and more nearly to the zero of absolute temperature he will encounter phenomena compelling modification, revision, and refinement of formulas which fairly covered the facts previously known. Just as nearly seventy years ago chemists were waiting for some means of getting a temperature of 100° below melting ice, so ten years ago they were casting about for the means of going 100° lower still. The difficulty, it need hardly be said, increases in a geometrical rather than in an arithmetical ratio. Its magnitude may be estimated from the fact that to produce liquid air in the atmosphere of an ordinary laboratory is a feat analogous to the production of liquid water starting from steam at a white heat and working with all the implements and surroundings at the same high temperature. The problem was not so much how to produce intense cold as how to save it when produced from being immediately leveled up by the relatively superheated surroundings. Ordinary nonconducting packings were inadmissible because they are both cumbrous and opaque, while in working near the limits of our resources it is essential that the product should be visible and readily handled. It was while puzzling over this mechanical and manipulative difficulty in 1892 that it occurred to me that the principle of an arrangement used nearly twenty years before in some calorimetric experiments,[a] which was based upon the work of Dulong and Petit on radiation, might be employed with advantage as well to protect cold substances from heat as hot ones from rapid cooling. I therefore tried the effect of keeping liquefied gases in vessels having a double wall, the annular space between being very highly exhausted.[b] Experiments showed that liquid air evaporated at

[a] "On the physical constants of hydrogenium," Trans. Roy. Soc., ed. 1873.

[b] It now appears that similar vessels were employed by Professor Violle in a research entitled "Sur un calorimètre par refroidissement," Comp. Rendu, 1882.

only one-fifth of the rate prevailing when it was placed in a similar unexhausted vessel, owing to the convective transference of heat by the gas particles being enormously reduced by the high vacuum. But, in addition, these vessels lend themselves to an arrangement by which radiant heat can also be cut off. It was found that when the inner walls were coated with a bright deposit of silver the influx of heat was diminished to one-sixth the amount entering without the metallic coating. The total effect of the high vacuum and the silvering is to reduce the ingoing heat to about 3 per cent. The efficiency of such vessels depends upon getting as high a vacuum as possible, and cold is one of the best means of effecting the desired exhaustion. All that is necessary is to fill completely the space that has to be exhausted with an easily condensable vapor, and then to freeze it out in a receptacle attached to the primary vessel that can be sealed off. The advantage of this method is that no air pump is required and that theoretically there is no limit to the degree of exhaustion that can be obtained. The action is rapid, provided liquid air is the cooling agent, and vapors like mercury, water, or benzol are employed. It is obvious that when we have to deal with such an exceptionally volatile liquid as hydrogen, the vapor filling may be omitted because air itself is now an easily condensable vapor. In other words, liquid hydrogen, collected in such vessels with the annular space full of air, immediately solidifies the air and thereby surrounds itself with a high vacuum. In the same way, when it shall be possible to collect a liquid boiling on the absolute scale at about 5°, as compared with the 20° of hydrogen, then you might have the annular space filled with the latter gas to begin with, and yet get directly a very high vacuum, owing to the solidification of the hydrogen. Many combinations of vacuum vessels can be arranged, and the lower the temperature at which we have to operate the more useful they become. Vessels of this kind are now in general use, and in them liquid air has crossed the American continent. Of the various forms, that variety is of special importance which has a spiral tube joining the bottom part of the walls, so that any liquid gas may be drawn off from the interior of such a vessel. In the working of regenerative coils such a device becomes all important, and such special vessels can not be dispensed with for the liquefaction of hydrogen.

In the early experiments of Pictet and Cailletet, cooling was produced by the sudden expansion of the highly compressed gas preferably at a low temperature, the former using a jet that lasted for some time, the latter an instantaneous adiabatic expansion in a strong glass tube. Neither process was practicable as a mode of producing liquid gases, but both gave valuable indications of partial change into the liquid state by the production of a temporary mist. Linde, however, saw that the continuous use of a jet of highly compressed gas, combined with regenerative cooling, must lead to liquefaction on account of what is called the Kelvin-Joule effect; and he succeeded in making a machine,

based on this principle, capable of producing liquid air for industrial purposes. These experimenters had proved that, owing to molecular attraction, compressed gases passing through a porous plug or small aperture were lowered in temperature by an amount depending on the difference of pressure and inversely as the square of the absolute temperature. This means that for a steady difference of pressure the cooling is greater the lower the temperature. The only gas that did not show cooling under such conditions was hydrogen. Instead of being cooled it became actually hotter. The reason for this apparent anomaly in the Kelvin-Joule effect is that every gas has a thermometric point of inversion above which it is heated and below which it is cooled. This inversion point, according to van der Waals, is six and three-quarter times the critical point. The efficiency of the Linde process depends on working with highly compressed gas well below the inversion temperature, and in this respect this point may be said to take the place of the critical one, when in the ordinary way direct liquefaction is being effected by the use of specific liquid cooling agents. The success of both processes depends upon working within a certain temperature range, only the Linde method gives us a much wider range of temperature within which liquefaction can be effected. This is not the case if, instead of depending on getting cooling by the internal work done by the attraction of the gas molecules, we force the compressed gas to do external work as in the well-known air machines of Kirk and Coleman. Both these inventors have pointed out that there is no limit of temperature, short of liquefaction of the gas in use in the circuit, that such machines are not capable of giving. While it is theoretically clear that such machines ought to be capable of maintaining the lowest temperatures, and that with the least expenditure of power, it is a very different matter to overcome the practical difficulties of working such machines under the conditions. Coleman kept a machine delivering air at minus 83° for hours, but he did not carry his experiments any further. Recently M. Claude, of Paris, has, however, succeeded in working a machine of this type so efficiently that he has managed to produce 1 liter of liquid air per horsepower expended per hour in the running of the engine. This output is twice as good as that given by the Linde machine, and there is no reason to doubt that the yield will be still further improved. It is clear, therefore, that in the immediate future the production of liquid air and hydrogen will be effected most economically by the use of machines producing cold by the expenditure of mechanical work.

LIQUID HYDROGEN AND HELIUM.

To the physicist the copious production of liquid air by the methods described was of peculiar interest and value as affording the means of attacking the far more difficult problem of the liquefaction of hydrogen, and even as encouraging the hope that liquid hydrogen might in

time be employed for the liquefaction of yet more volatile elements, apart from the importance which its liquefaction must hold in the process of the steady advance toward the absolute zero. Hydrogen is an element of especial interest, because the study of its properties and chemical relations led great chemists like Faraday, Dumas, Daniell, Graham, and Andrews to entertain the view that if it could ever be brought into the state of liquid or solid it would reveal metallic characters. Looking to the special chemical relations of the combined hydrogen in water, alkaline oxides, acids, and salts, together with the behavior of these substances on electrolysis, we are forced to conclude that hydrogen behaves as the analogue of a metal. After the beautiful discovery of Graham that palladium can absorb some hundreds of times its own volume of hydrogen, and still retain its luster and general metallic character, the impression that hydrogen was probably a member of the metallic group became very general. The only chemist who adopted another view was my distinguished predecessor, Professor Odling. In his Manual of Chemistry, published in 1861, he pointed out that hydrogen has chlorous as well as basic relations, and that they are as decided, important, and frequent as its other relations. From such considerations he arrived at the conclusion that hydrogen is essentially a neutral or intermediate body, and therefore we should not expect to find liquid or solid hydrogen possess the appearance of a metal. This extraordinary prevision, so characteristic of Odling, was proved to be correct some thirty-seven years after it was made. Another curious anticipation was made by Dumas, in a letter addressed to Pictet, in which he says that the metal most analogous to hydrogen is magnesium, and that probably both elements have the same atomic volume, so that the density of hydrogen, for this reason, would be about the value elicited by subsequent experiments. Later on, in 1872, when Newlands began to arrange the elements in periodic groups, he regarded hydrogen as the lowest member of the chlorine family; but Mendeleef, in his later classification, placed hydrogen in the group of the alkaline metals; on the other hand, Dr. Johnstone Stoney classes hydrogen with the alkaline earth metals and magnesium. From this speculative divergency it is clear no definite conclusion could be reached regarding the physical properties of liquid or solid hydrogen, and the only way to arrive at the truth was to prosecute low-temperature research until success attended the efforts to produce its liquefaction. This result I definitely obtained in 1898. The case of liquid hydrogen is, in fact, an excellent illustration of the truth already referred to, that no theoretical forecast, however apparently justified by analogy, can be finally accepted as true until confirmed by actual experiment. Liquid hydrogen is a colorless transparent body of extraordinary intrinsic interest. It has a clearly defined surface, is easily seen, drops well, in spite of the fact that its

surface tension is only the thirty-fifth part of that of water, or about one-fifth that of liquid air, and can be poured easily from vessel to vessel. The liquid does not conduct electricity, and, if anything, is slightly diamagnetic. Compared with an equal volume of liquid air, it requires only one-fifth the quantity of heat for vaporization; on the other hand, its specific heat is six times that of liquid air or three times that of water. The coefficient of expansion of the fluid is remarkable, being about ten times that of the gas. It is by far the lightest liquid known to exist, its density being only one-fourteenth that of water. The lightest liquid previously known was liquid marsh gas, which is six times heavier. The only solid which has so small density as to float upon its surface is a piece of pith wood. It is by far the coldest liquid known. At ordinary atmospheric pressure it boils at minus 252.5° or 20.5° absolute. The critical point of the liquid is from 30° to 32° absolute, and the critical pressure not more but probably less than fifteen atmospheres. The vapor of the hydrogen arising from the liquid has nearly the density of air; that is, it is fourteen times that of the gas at the ordinary temperature. Reduction of the pressure by an air pump brings down the temperature to minus 258°, when the liquid becomes a solid resembling frozen foam, and this by further exhaustion is cooled to minus 259.5° or 13.5° absolute, which is the lowest steady temperature that has been reached. The solid may also be got in the form of a clear transparent ice, melting at about 15° absolute, under a pressure of 55 mm., possessing the unique density of one-tenth that of water. Such cold involves the solidification of every gaseous substance but one that is at present definitely known to the chemist, and so liquid hydrogen introduces the investigator to a world of solid bodies. The contrast between this refrigerating substance and liquid air is most remarkable. On the removal of the loose plug of cotton wool used to cover the mouth of the vacuum vessel in which it is stored, the action is followed by a miniature snowstorm of solid air, formed by the freezing of the atmosphere at the point where it comes into contact with the cold vapor rising from the liquid. This solid air falls into the vessel and accumulates as a white snow at the bottom of the liquid hydrogen. When the outside of an ordinary test tube is cooled by immersion in the liquid, it is soon observed to fill up with solid air, and if the tube be now lifted out a double effect is visible, for liquid air is produced both in the inside and on the outside of the tube—in the one case by the melting of the solid and in the other by condensation from the atmosphere. A tuft of cotton wool soaked in the liquid and then held near the pole of a strong magnet is attracted, and it might be inferred therefrom that liquid hydrogen is a magnetic body. This, however, is not the case. The attraction is due neither to the cotton wool nor to the hydrogen—which indeed evaporates almost as soon as the tuft

is taken out of the liquid—but to the oxygen of the air, which is well known to be a magnetic body, frozen in the wool by the extreme cold.

The strong condensing powers of liquid hydrogen afford a simple means of producing vacua of very high tenuity. When one end of a sealed tube containing ordinary air is placed for a short time in the liquid, the contained air accumulates as a solid at the bottom, while the higher part is almost entirely deprived of particles of gas. So perfect is the vacuum thus formed, that the electric discharge can be made to pass only with the greatest difficulty. Another important application of liquid air, liquid hydrogen, etc., is as analytic agents. Thus, if a gaseous mixture be cooled by means of liquid oxygen only those constituents will be left in the gaseous state which are less condensable than oxygen. Similarly, if this gaseous residue be in its turn cooled in liquid hydrogen a still further separation will be effected, everything that is less volatile than hydrogen being condensed to a liquid or solid. By proceeding in this fashion it has been found possible to isolate helium from a mixture in which it is present to the extent of only one part in one thousand. By the evaporation of solid hydrogen under the air pump we can reach within 13° or 14° of the zero, but there or thereabouts our progress is barred. This gap of 13° might seem at first sight insignificant in comparison with the hundreds that have already been conquered. But to win one degree low down the scale is quite a different matter from doing so at higher temperatures. In fact, to annihilate these few remaining degrees would be a far greater achievement than any so far accomplished in low-temperature research. For the difficulty is twofold, having to do partly with process and partly with material. The application of the methods used in the liquefaction of gases becomes continually harder and more troublesome as the working temperature is reduced; thus, to pass from liquid air to liquid hydrogen—a difference of 60°—is, from a thermodynamic point of view, as difficult as to bridge the gap of 150° that separates liquid chlorine and liquid air. By the use of a new liquid gas exceeding hydrogen in volatility to the same extent as hydrogen does nitrogen, the investigator might get to within 5° of the zero; but even a second hypothetical substance, again exceeding the first one in volatility to an equal extent, would not suffice to bring him quite to the point of his ambition. That the zero will ever be reached by man is extremely improbable. A thermometer introduced into regions outside the uttermost confines of the earth's atmosphere might approach the absolute zero, provided that its parts were highly transparent to all kinds of radiation; otherwise it would be affected by the radiation of the sun, and would therefore become heated. But supposing all difficulties to be overcome, and the experimenter to be able to reach within a few degrees of the

zero, it is by no means certain that he would find the near approach of the death of matter sometimes pictured. Any forecast of the phenomena that would be seen must be based on the assumption that there is continuity between the processes studied at attainable temperatures and those which take place at still lower ones. Is such an assumption justified? It is true that many changes in the properties of substances have been found to vary steadily with the degree of cold to which they are exposed. But it would be rash to take for granted that the changes which have been traced in explored regions continue to the same extent and in the same direction in those which are as yet unexplored. Of such a breakdown low-temperature research has already yielded a direct proof at least in one case. A series of experiments with pure metals showed that their electrical resistance gradually decreases as they are cooled to lower and lower temperatures, in such ratio that it appeared probable that at the zero of absolute temperature they would have no resistance at all and would become perfect conductors of electricity. This was the inference that seemed justifiable by observations taken at depths of cold which can be obtained by means of liquid air and less powerful refrigerants. But with the advent of the more powerful refrigerant liquid hydrogen it became necessary to revise that conclusion. A discrepancy was first observed when a platinum resistance thermometer was used to ascertain the temperature of that liquid boiling under atmospheric and reduced pressure. All known liquids, when forced to evaporate quickly by being placed in the exhausted receiver of an air pump, undergo a reduction in temperature, but when hydrogen was treated in this way it appeared to be an exception. The resistance thermometer showed no such reduction as was expected, and it became a question whether it was the hydrogen or the thermometer that was behaving abnormally. Ultimately, by the adoption of other thermometrical appliances, the temperature of the hydrogen was proved to be lowered by exhaustion, as theory indicated. Hence it was the platinum thermometer which had broken down; in other words, the electrical resistance of the metal employed in its construction was not, at temperatures about minus 250° C, decreased by cold in the same proportion as at temperatures about minus 200°. This being the case, there is no longer any reason to suppose that at the absolute zero platinum would become a perfect conductor of electricity; and in view of the similarity between the behavior of platinum and that of other pure metals in respect of temperature and conductivity, the presumption is that the same is true of them also. At any rate, the knowledge that in the case of at least one property of matter we have succeeded in attaining a depth of cold sufficient to bring about unexpected change in the law expressing the variation of that property with temperature, is sufficient to show the

the necessity for extreme caution in extending our inferences regarding the properties of matter near the zero of temperature. Lord Kelvin evidently anticipates the possibility of more remarkable electrical properties being met with in the metals near the zero. A theoretical investigation on the relation of "electrions" and atoms has led him to suggest a hypothetical metal having the following remarkable properties: Below 1° absolute it is a perfect insulator of electricity; at 2° it shows noticeable conductivity, and at 6° it possesses high conductivity. It may safely be predicted that liquid hydrogen will be the means by which many obscure problems of physics and chemistry will ultimately be solved, so that the liquefaction of the last of the old permanent gases is as pregnant now with future consequences of great scientific moment as was the liquefaction of chlorine in the early years of the last century.

The next step toward the absolute zero is to find another gas more volatile than hydrogen, and that we possess in the gas occurring in clevite, identified by Ramsay as helium, a gas which is widely distributed, like hydrogen, in the sun, stars, and nebulæ. A specimen of this gas was subjected by Olszewski to liquid air temperatures, combined with compression and subsequent expansion, following the Cailletet method, and resulted in his being unable to discover any appearance of liquefaction, even in the form of mist. His experiments led him to infer that the boiling point of the substance is probably below 9° absolute. After Lord Rayleigh had found a new source of helium in the gases which are derived from the Bath springs, and liquid hydrogen became available as a cooling agent, a specimen of helium cooled in liquid hydrogen showed the formation of fluid, but this turned out to be owing to the presence of an unknown admixture of other gases. As a matter of fact, a year before the date of this experiment I had recorded indications of the presence of unknown gases in the spectrum of helium derived from this source. When subsequently such condensable constituents were removed, the purified helium showed no signs of liquefaction, even when compressed to 80 atmospheres, while the tube containing it was surrounded with solid hydrogen. Further, on suddenly expanding, no instantaneous mist appeared. Thus helium was definitely proved to be a much more volatile substance than hydrogen in either the liquid or solid condition. The inference to be drawn from the adiabatic expansion effected under the circumstances is that helium must have touched a temperature of from 9° to 10° for a short time without showing any signs of liquefaction, and consequently that the critical point must be still lower. This would force us to anticipate that the boiling point of the liquid will be about 5° absolute, or liquid helium will be four times more volatile than liquid hydrogen, just as liquid hydrogen is four times more volatile than liquid air. Although the liquefaction of the

gas is a problem for the future, this does not prevent us from anticipating some of the properties of the fluid body. It would be twice as dense as liquid hydrogen if the ratio of the critical constants has the same value as in the case of hydrogen that is to say, the critical pressure will not exceed 4 or 5 atmospheres. The liquid would on this assumption possess a very feeble surface tension, and its compressibility and expansibility would be about four times that of liquid hydrogen, while the heat required to vaporize the molecule would be about one-fourth that of liquid hydrogen. If the critical pressure should turn out to be as high as that of nitrogen or oxygen, then the fluid density would exceed that of water, and the surface tension increased, while the compressibility would be diminished. Heating the liquid 1° above its boiling point would raise the pressure by $1\frac{3}{4}$ atmospheres, which is more than four times the increment for liquid hydrogen. The liquid would be only seventeen times denser than its vapor, whereas liquid hydrogen is sixty-five times denser than the gas it gives off. Only some 3° or 4° would separate the critical temperature from the boiling point and the melting point, whereas in liquid hydrogen the separation is respectively 10° and 15°. As the liquid refractivities for oxygen, nitrogen, and hydrogen are closely proportional to the gaseous values, and as Lord Rayleigh has shown that helium has only one-fourth the refractivity of hydrogen, although it is twice as dense, we may infer that the refractivity of liquid helium would also be about one-fourth that of liquid hydrogen, unless the critical pressure is high, which would necessitate an increase in the value. Now hydrogen has the smallest refractivity of any known liquid, and yet liquid helium will have only about one-fourth of this value —comparable in fact with liquid hydrogen just below its critical point. This means that the liquid will be quite exceptional in its optical properties, and very difficult to see. This may be the explanation why no mist has been seen on its adiabatic expansion from the lowest temperatures. Taking all these remarkable properties of the liquid into consideration, one is afraid to predict that we are at present able to cope with the difficulties involved in its production and collection. Provided the critical point is, however, not below 8° absolute, then from the knowledge of the conditions that are successful in producing a change of state in hydrogen through the use of liquid air, we may safely predict that helium can be liquefied by following similar methods. If, however, the critical point is as low as 6° absolute, then it would be almost hopeless to anticipate success by adopting the process that works so well with hydrogen. The present anticipation is that the gas will succumb after being subjected to this process, only, instead of liquid air under exhaustion being used as the primary cooling agent, liquid hydrogen evaporating under similar circumstances must be employed. In this case the resulting liquid would require to

be collected in a vacuum vessel the outer walls of which are immersed in liquid hydrogen. The practical difficulties and the cost of the operation will be very great; but on the other hand, the descent to a temperature within 5° of the zero would open out new vistas of scientific inquiry which would add immensely to our knowledge of the properties of matter. To command in our laboratories a temperature which would be equivalent to that which a comet might reach at an infinite distance from the sun would indeed be a great triumph for science. If the present Royal Institution attack on helium should fail, then we must ultimately succeed by adopting a process based on the mechanical production of cold through the performance of external work. When a turbine can be worked by compressed helium, the whole of the mechanism and circuits being kept surrounded with liquid hydrogen, then we need hardly doubt that the liquefaction will be effected. In all probability gases other than helium will be discovered of greater volatility than hydrogen. It was at the British Association meeting, in 1896, that I made the first suggestion of the probable existence of an unknown element which would be found to fill up the gap between argon and helium, and this anticipation was soon taken up by others and ultimately confirmed. Later, in the Bakerian Lecture for 1901, I was led to infer that another member of the helium group might exist having the atomic weight about 2, and this would give us a gas still more volatile with which the absolute zero might be still more nearly approached. It is to be hoped that some such element or elements may yet be isolated and identified as coronium or nebulium. If among the unknown gases possessing a very low critical point some have a high critical pressure instead of a low one, which ordinary experience would lead us to anticipate, then such difficultly liquefiable gases would produce fluids having different physical properties from any of those with which we are acquainted. Again, gases may exist having smaller atomic weights and densities than hydrogen, yet all such gases must, according to our present views of the gaseous state, be capable of liquefaction before the zero of temperature is reached. The chemists of the future will find ample scope for investigation within the apparently limited range of temperature which separates solid hydrogen from the zero. Indeed, great as is the sentimental interest attached to the liquefaction of these refractory gases, the importance of the achievement lies rather in the fact that it opens out new fields of research and enormously widens the horizon of physical science, enabling the natural philosopher to study the properties and behavior of matter under entirely novel conditions. This department of inquiry is as yet only in its infancy, but speedy and extensive developments may be looked for, since within recent years several special cryogenic laboratories have been established for the prosecution of such researches, and a liquid-air plant is becoming a common adjunct to the equipment of the ordinary laboratory.

THE UPPER AIR AND AURORAS.

The present liquid ocean, neglecting everything for the moment but the water, was at a previous period of the earth's history part of the atmosphere, and its condensation has been brought about by the gradual cooling of the earth's surface. This resulting ocean is subjected to the pressure of the remaining uncondensed gases, and as these are slightly soluble they dissolve to some extent in the fluid. The gases in solution can be taken out by distillation or by exhausting the water, and if we compare their volume with the volume of the water as steam, we should find about 1 volume of air in 60,000 volumes of steam. This would then be about the rough proportion of the relatively permanent gas to condensable gas which existed in the case of the vaporized ocean. Now let us assume the surface of the earth gradually cooled to some 200 below the freezing point; then, after all the present ocean was frozen and the climate became three times more intense than any arctic frost, a new ocean of liquid air would appear, covering the entire surface of the frozen globe about 35 feet deep. We may now apply the same reasoning to the liquid-air ocean that we formerly did to the water one, and this would lead us to anticipate that it might contain in solution some gases that may be far less condensable than the chief constituents of the fluid. In order to separate them we must imitate the method of taking the gases out of water. Assume a sample of liquid air cooled to the low temperature that can be reached by its own evaporation, connected by a pipe to a condenser cooled in liquid hydrogen; then any volatile gases present in solution will distill over with the first portions of the air, and can be pumped off, being uncondensable at the temperature of the condenser. In this way a gas mixture, containing, of the known gases, free hydrogen, helium, and neon, has been separated from liquid air. It is interesting to note in passing that the relative volatilities of water and oxygen are in the same ratio as those of liquid air and hydrogen, so that the analogy between the ocean of water and that of liquid air has another suggestive parallel. The total uncondensable gas separated in this way amounts to about one fifty-thousandth of the volume of the air, which is about the same proportion as the air dissolved in water. That free hydrogen exists in air in small amount is conclusively proved, but the actual proportion found by the process is very much smaller than Gautier has estimated by the combustion method. The recent experiments of Lord Rayleigh show that Gautier, who estimated the hydrogen present as one five-thousandth, has in some way produced more hydrogen than he can manage to extract from pure air by a repetition of the same process. The spectroscopic examination of these gases throws new light upon the question of the aurora and the nature of the upper air. On passing electric discharges through the tubes containing the most volatile of the atmospheric gases, they glow with a bright orange light, which

is especially marked at the negative pole. The spectroscope shows that this light consists, in the visible part of the spectrum, chiefly of a succession of strong rays in the red, orange, and yellow, attributed to hydrogen, helium, and neon. Besides these, a vast number of rays, generally less brilliant, are distributed through the whole length of the visible spectrum. The greater part of these rays are of, as yet, unknown origin. The violet and ultraviolet part of the spectrum rivals in strength that of the red and yellow rays. As these gases probably include some of the gases that pervade interplanetary space, search was made for the prominent nebular, coronal, and auroral lines. No definite lines agreeing with the nebular spectrum could be found, but many lines occurred closely coincident with the coronal and auroral spectrum. But before discussing the spectroscopic problem it will be necessary to consider the nature and condition of the upper air.

According to the old law of Dalton, supported by the modern dynamical theory of gases, each constituent of the atmosphere while acted upon by the force of gravity forms a separate atmosphere, completely independent, except as to temperature, of the others, and the relations between the common temperature and the pressure and altitude for each specific atmosphere can be definitely expressed. If we assume the altitude and temperature known, then the pressure can be ascertained for the same height in the case of each of the gaseous constituents, and in this way the percentage composition of the atmosphere at that place may be deduced. Suppose we start with a surface atmosphere having the composition of our air, only containing two ten-thousandths of hydrogen, then at 37 miles, if a sample could be procured for analysis, we believe that it would be found to contain 12 per cent of hydrogen and only 10 per cent of oxygen. The carbonic acid practically disappears, and by the time we reach 47 miles, where the temperature is minus 132°, assuming a gradient of 3.2° per mile, the nitrogen and oxygen have so thinned out that the only constituent of the upper air which is left is hydrogen. If the gradient of temperature were doubled, the elimination of the nitrogen and oxygen would take place by the time 37 miles was reached, with a temperature of minus 220°. The permanence of the composition of the air at the highest altitudes, as deduced from the basis of the dynamical theory of gases, has been discussed by Stoney, Bryan, and others. It would appear that there is a consensus of opinion that the rate at which gases like hydrogen and helium could escape from the earth's atmosphere would be excessively slow. Considering that to compensate any such loss the same gases are being supplied by actions taking place in the crust of the earth, we may safely regard them as necessarily permanent constituents of the upper air. The temperature at the elevations we have been discussing would not be sufficient to cause any liquefaction of the nitrogen and oxygen, the pressure being so low. If we assume the mean temper-

ature as about the boiling point of oxygen at atmospheric pressure, then a considerable amount of the carbonic acid must solidify as a mist, if the air from a lower level be cooled to this temperature; and the same result might take place with other gases of relatively small volatility which occur in air. This would explain the clouds that have been seen at an elevation of 50 miles, without assuming the possibility of water vapor being carried up so high. The temperature of the upper air must be above that on the vapor pressure curve corresponding to the barometric pressure at the locality, otherwise liquid condensation must take place. In other words, the temperature must be above the dew point of air at that place. At higher elevations, on any reasonable assumption of temperature distribution, we inevitably reach a temperature where the air would condense, just as Fourier and Poisson supposed it would, unless the temperature is arrested in some way from approaching the zero. Both ultra-violet absorption and the prevalence of electric storms may have something to do with the maintenance of a higher mean temperature. The whole mass of the air above 40 miles is not more than one seven-hundredth part of the total mass of the atmosphere, so that any rain or snow of liquid or solid air, if it did occur, would necessarily be of a very tenuous description. In any case, the dense gases tend to accumulate in the lower strata, and the lighter ones to predominate at the higher altitudes, always assuming that a steady state of equilibrium has been reached. It must be observed, however, that a sample of air taken at an elevation of 9 miles has shown no difference in composition from that at the ground, whereas, according to our hypothesis, the oxygen ought to have been diminished to 17 per cent, and the carbonic acid should also have become much less. This can only be explained by assuming that a large intermixture of different layers of the atmosphere is still taking place at this elevation. This is confirmed by a study of the motions of clouds about 6 miles high, which reveals an average velocity of the air currents of some 70 miles an hour; such violent winds must be the means of causing the intermingling of different atmospheric strata. Some clouds, however, during hot and thundery weather, have been seen to reach an elevation of 17 miles, so that we have direct proof that on occasion the lower layers of atmosphere are carried to a great elevation. The existence of an atmosphere at more than 100 miles above the surface of the earth is revealed to us by the appearance of meteors and fireballs, and when we can take photographs of the spectrum of such apparitions we shall learn a great deal about the composition of the upper air. In the meantime Pickering's solitary spectrum of a meteor reveals an atmosphere of hydrogen and helium, and so far this is corroborative of the doctrine we have been discussing. It has long been recognized that the aurora is the result of electric discharges within the limits of the earth's atmosphere, but it was

difficult to understand why its spectrum should be so entirely different from anything which could be produced artificially by electric discharges through rarefied air at the surface of the earth. Writing in 1879, Rand Capron, after collecting all the recorded observations, was able to enumerate no more than nine auroral rays, of which but one could with any probability be identified with rays emitted by atmospheric air under an electric discharge. Vogel attributed this want of agreement between nature and experiment, in a vague way, to difference of temperature and pressure; and Zollner thought the auroral spectrum to be one of a different order, in the sense in which the line and band spectra of nitrogen are said to be of different orders. Such statements were merely confessions of ignorance. But since that time observations of the spectra of auroras have been greatly multiplied, chiefly through the Swedish and Danish polar expeditions, and the length of spectrum recorded on the ultra-violet side has been greatly extended by the use of photography, so that, in a recent discussion of the results, M. Henri Stassano is able to enumerate upward of one hundred auroral rays, of which the wave length is more or less approximately known, some of them far in the ultra-violet. Of this large number of rays he is able to identify, within the probable limits of errors of observation, about two-thirds as rays, which Professor Liveing and myself have observed to be emitted by the most volatile gases of atmospheric air unliquefiable at the temperature of liquid hydrogen. Most of the remainder he ascribes to argon, and some he might, with more probability, have identified with krypton or xenon rays, if he had been aware of the publication of wave lengths of the spectra of those gases, and the identification of one of the highest rays of krypton with that most characteristic of auroras. The rosy tint often seen in auroras, particularly in the streamers, appears to be due mainly to neon, of which the spectrum is remarkably rich in red and orange rays. One or two neon rays are among those most frequently observed, while the red ray of hydrogen and one red ray of krypton have been noticed only once. The predominance of neon is not surprising, seeing that from its relatively greater proportion in air and its low density it must tend to concentrate at higher elevations. So large a number of probable identifications warrants the belief that we may yet be able to reproduce in our laboratories the auroral spectrum in its entirety. It is true that we have still to account for the appearance of some, and the absence of other, rays of the newly discovered gases, which in the way in which we stimulate them appear to be equally brilliant, and for the absence, with one doubtful exception, of all the rays of nitrogen. If we can not give the reason of this, it is because we do not know the mechanism of luminescence—nor even whether the particles which carry the electricity are themselves luminous, or whether they only produce stresses causing other particles

which encounter them to vibrate; yet we are certain that an electric discharge in a highly rarefied mixture of gases lights one element and not another, in a way which, to our ignorance, seems capricious. The Swedish North Polar Expedition concluded from a great number of trigonometrical measurements that the average above the ground of the base of the aurora was 50 kilometers (34 miles) at Cape Thorsden, Spitzbergen; at this height the pressure of the nitrogen of the atmosphere would be only about one-tenth of a millimeter, and Moissan and Deslandres have found that in atmospheric air at pressures less than 1 mm. the rays of nitrogen and oxygen fade and are replaced by those of argon and by five new rays which Stassano identifies with rays of the more volatile gases measured by us. Also Collie and Ramsay's observations on the distance to which electrical discharges of equal potential traverse different gases explosively throw much light on the question; for they find that, while for helium and neon this distance is from 250 to 300 mm., for argon it is 45½ mm., for hydrogen it is 39 mm., and for air and oxygen still less. This indicates that a good deal depends on the very constitution of the gases themselves, and certainly helps us to understand why neon and argon, which exist in the atmosphere in larger proportions than helium, krypton, or xenon, should make their appearance in the spectrum of auroras almost to the exclusion of nitrogen and oxygen. How much depends not only on the constitution and it may be temperature of the gases, but also on the character of the electric discharge, is evident from the difference between the spectra at the cathode and anode in different gases, notably in nitrogen and argon, and not less remarkably in the more volatile compounds of the atmosphere. Paulsen thinks the auroral spectrum wholly due to cathodic rays. Without stopping to discuss that question, it is certain that changes in the character of the electric discharge produce definite changes in the spectra excited by them. It has long been known that in many spectra the rays which are inconspicuous with an uncondensed electric discharge become very pronounced when a Leyden jar is in the circuit. This used to be ascribed to a higher temperature in this condensed spark, though measurements of that temperature have not borne out the explanation. Schuster and Hemsalech have shown that these changes of spectra are in part due to the oscillatory character of the condenser discharge which may be enhanced by self-induction, and the corresponding change of spectrum thereby made more pronounced. Lightning we should expect to resemble condensed discharge much more than aurora, but this is not borne out by the spectrum. Pickering's recent analysis of the spectrum of a flash obtained by photography shows, out of nineteen lines measured by him, only two which can be assigned with probability to nitrogen and oxygen, while three hydrogen rays most likely due to water are very conspicuous, and

eleven may be reasonably ascribed to argon, krypton, and xenon, one to more volatile gas of the neon class, and the brightest ray of all is but a very little less refrangible than the characteristic auroral ray, and coincides with a strong ray of calcium, but also lies between, and close to, an argon and a neon ray, neither of them weak rays. There may be some doubt about the identification of the spectral rays of auroras because of the wide limits of the probable errors in measuring wave lengths so faint as most of them are, but there is no such doubt about the wave lengths of the rays in solar protuberances measured by Deslandres and Hale. Stassano found that these rays, forty-four in number, lying between the Fraunhofer line *F* and 3148 in the ultra-violet agree very closely with rays which Professor Liveing and myself measured in the spectra of the most volatile atmospheric gases. It will be remembered that one of the earliest suggestions as to the nature of solar prominences was that they were solar auroras. This supposition helped to explain the marvelous rapidity of their changes, and the apparent suspension of brilliant self-luminous clouds at enormous heights above the sun's surface. Now, the identification of the rays of their spectra with those of the most volatile gases, which also furnish many of the auroral rays, certainly supports that suggestion. A stronger support, however, seems to be given to it by the results obtained at the total eclipse of May, 1901, by the American expedition to Sumatra. In the Astrophysical Journal for June last is a list of 339 lines in the spectrum of the corona photographed by Humphreys, during totality, with a very large concave grating. Of these no fewer than 209 do not differ from lines we have measured in the most volatile gases of the atmosphere, or in krypton or xenon, by more than one unit of wave length on Armstrong's scale, a quantity within the limit of probable error. Of the remainder, a good many agree to a like degree with argon lines, a very few with oxygen lines, and still fewer with nitrogen lines; the characteristic green auroral ray, which is not in the range of Humphreys's photographs, also agrees within a small fraction of a unit of wave length with one of the rays emitted by the most volatile atmospheric gas. Taking into account the Fraunhofer lines *H*, *K*, and *G*, usually ascribed to calcium, there remain only 55 lines of the 339 unaccounted for to the degree of probability indicated. Of these considerably more than half are very weak lines which have not depicted themselves on more than one of the six films exposed, and extend but a very short distance into the sun's atmosphere. There are, however, seven which are stronger lines, and reach to a considerable height above the sun's rim, and all have depicted themselves on at least four of the six films. If there be no considerable error in the wave lengths assigned (and such is not likely to be the case), these lines may perhaps be due to some volatile element which may yet be discovered in our atmosphere. However that may be, the very great

number of close coincidences between the auroral rays and those which are emitted under electric excitement by gases of our atmosphere almost constrains us to believe, what is indeed most probable on other grounds, that the sun's coronal atmosphere is composed of the same substances as the earth's, and that it is rendered luminous in the same way — namely, by electric discharges. This conclusion has plainly an important bearing on the explanation which should be given of the outburst of new stars and of the extraordinary and rapid changes in their spectra. Moreover, leaving on one side the question whether gases ever become luminous by the direct action of heat, apart from such transfers of energy as occur in chemical change and electric disturbance, it demands a revision of the theories which attribute more permanent differences between the spectra of different stars to differences of temperature, and a fuller consideration of the question whether they can not with better reason be explained by differences in the electric conditions which prevail in the stellar atmosphere.

If we turn to the question what is the cause of the electric discharges which are generally believed to occasion auroras, but of which little more has hitherto been known than that they are connected with sun spots and solar eruptions, recent studies of electric discharges in high vacua, with which the names of Crookes, Röntgen, Lenard, and J. J. Thomson will always be associated, have opened the way for Arrhenius to suggest a definite and rational answer. He points out that the frequent disturbances which we know to occur in the sun must cause electric discharges in the sun's atmosphere far exceeding any that occur in that of the earth. These will be attended with an ionisation of the gases, and the negative ions will stream away through the outer atmosphere of the sun into the interplanetary space, becoming, as Wilson has shown, nuclei of aggregation of condensable vapors and cosmic dust. The liquid and solid particles thus formed will be of various sizes; the larger will gravitate back to the sun, while those with diameters less than one and a half thousandths of a millimeter, but nevertheless greater than a wave-length of light, will, in accordance with Clerk-Maxwell's electro-magnetic theory, be driven away from the sun by the incidence of the solar rays upon them, with velocities which may become enormous, until they meet other celestial bodies, or increase their dimensions by picking up more cosmic dust or diminish them by evaporation. The earth will catch its share of such particles on the side which is turned toward the sun, and its upper atmosphere will thereby become negatively electrified until the potential of the charge reaches such a point that a discharge occurs, which will be repeated as more charged particles reach the earth. This theory not only accounts for the auroral discharges, and the coincidence of their times of greatest frequency with those of the maxima of sun spots, but also for the minor maxima and minima. The vernal and autumnal maxima occur when the line through the

earth and sun has its greatest inclination to the solar equator, so that the earth is more directly exposed to the region of maximum of sun spots, while the twenty-six days period corresponds closely with the period of rotation of that part of the solar surface where faculæ are most abundant. J. J. Thomson has pointed out, as a consequence of the Richardson observations, that negative ions will be constantly streaming from the sun merely regarded as a hot body, but this is not inconsistent with the supposition that there will be an excess of this emission in eruptions, and from the regions of faculæ. Arrhenius's theory accounts also, in a way which seems the most satisfactory hitherto enunciated, for the appearances presented by comets. The solid parts of these objects absorb the sun's rays, and as they approach the sun become heated on the side turned toward him until the volatile substances frozen in or upon them are evaporated and diffused in the gaseous state in surrounding space, where they get cooled to the temperature of liquefaction and aggregated in drops about the negative ions. The larger of these drops gravitate toward the sun and form clouds of the coma about the head, while the smaller are driven by the incidence of the sun's light upon them away from the sun and form the tail. The curvature of the tail depends, as Bredichin has shown, on the rate at which the particles are driven, which in turn depends on the size and specific gravity of the particles, and these will vary with the density of the vapor from which they are formed and the frequency of the negative ions which collect them. In any case Arrhenius's theory is a most suggestive one, not only with reference to auroras and comets, and the solar corona and chromosphere, but also as to the constitution of the photosphere itself.

VARIOUS LOW TEMPERATURE RESEARCHES.

We may now summarize some of the results which have already been attained by low-temperature studies. In the first place, the great majority of chemical interactions are entirely suspended, but an element of such exceptional powers of combination as fluorine is still active at the temperature of liquid air. Whether solid fluorine and liquid hydrogen would interact no one can at present say.[a] Bodies naturally become denser, but even a highly expansive substance like ice does not appear to reach the density of water at the lowest temperature. This is confirmatory of the view that the particles of matter under such conditions are not packed in the closest possible way. The force of cohesion is greatly increased at low temperatures, as is shown by the additional stress required to rupture metallic wires. This fact is of interest in connection with two conflicting theories of

[a] Note by author, April 16, 1903. In a recent communication to the French Academy by Professor Moissan and myself it is shown that violent combinations take place, so that chemical action can in certain cases take place near the zero of temperature. [See Comptes Rendus, March 30, 1903.]

matter. Lord Kelvin's view is that the forces that hold together the particles of bodies may be accounted for without assuming any other agency than gravitation or any other law than the Newtonian. An opposite view is that the phenomena of the aggregation of molecules depend upon the molecular vibration as a physical cause. Hence, at the zero of absolute temperature, this vibrating energy being in complete abeyance, the phenomena of cohesion should cease to exist, and matter generally be reduced to an incoherent heap of cosmic dust. This second view receives no support from experiment.

The photographic action of light is diminished at the temperature of liquid air to about 20 per cent of its ordinary efficiency, and at the still lower temperature of liquid hydrogen only about 10 per cent of the original sensitivity remains. At the temperature of liquid air or liquid hydrogen a large range of organic bodies and many inorganic ones acquire under exposure to violet light the property of phosphorescence. Such bodies glow faintly so long as they are kept cold, but become exceedingly brilliant during the period when the temperature is rising. Even solid air is a phosphorescent body. All the alkaline earth sulphides which phosphoresce brilliantly at the ordinary temperature lose this property when cooled, to be revived on heating; but such bodies in the first instance may be stimulated through the absorption of light at the lowest temperatures. Radio-active bodies, on the other hand, like radium, which are naturally self-luminous, maintain this luminosity unimpaired at the very lowest temperatures, and are still capable of inducing phosphorescence in bodies like the platino-cyanides. Some crystals become for a time self-luminous when cooled in liquid air or hydrogen, owing to the induced electric stimulation causing discharges between the crystal molecules. This phenomenon is very pronounced with nitrate of uranium and some platino-cyanides.

In conjunction with Professor Fleming a long series of experiments was made on the electric and magnetic properties of bodies at low temperatures. The subjects that have been under investigation may be classified as follows: The Thermo-Electric Powers of Pure Metals; the Magnetic Properties of Iron and Steel; Dielectric Constants; the Magnetic and Electric Constants of Liquid Oxygen; Magnetic Susceptibility.

The investigations have shown that electric conductivity in pure metals varies almost inversely as the absolute temperature down to minus 200°, but that this law is greatly affected by the presence of the most minute amount of impurity. Hence the results amount to a proof that electric resistance in pure metals is closely dependent upon the molecular or atomic motion which gives rise to temperature, and that the process by which the energy constituting what is called an electric current is dissipated essentially depends upon nonhomogeneity of structure and upon the absolute temperature of the material. It might be inferred that at the zero of absolute temperature resistance

would vanish altogether, and all pure metals become perfect conductors of electricity. This conclusion, however, has been rendered very doubtful by subsequent observations made at still lower temperatures, which appear to point to an ultimate finite resistance. Thus the temperature at which copper was assumed to have no resistance was minus 223°, but that metal has been cooled to minus 253° without getting rid of all resistance. The reduction in resistance of some of the metals at the boiling point of hydrogen is very remarkable. Thus copper has only 1 per cent, gold and platinum 3 per cent, and silver 4 per cent of the resistance they possessed at zero C., but iron still retains 12 per cent of its initial resistance. In the case of alloys and impure metals cold brings about a much smaller decrease in resistivity, and in the case of carbon and insulators like gutta-percha, glass, ebonite, etc., their resistivity steadily increases. The enormous increase in resistance of bismuth when transversely magnetized and cooled was also discovered in the course of these experiments. The study of dielectric constants at low temperatures has resulted in the discovery of some interesting facts. A fundamental deduction from Maxwell's theory is that the square of the refractive index of a body should be the same number as its dielectric constant. So far, however, from this being the case generally, the exceptions are far more numerous than the coincidences. It has been shown in the case of many substances, such as ice and glass, that an increase in the frequency of the alternating electromotive force results in a reduction of the dielectric constant to a value more consistent with Maxwell's law. By experiments upon many substances it is shown that even a moderate increase of frequency brings the large dielectric constant to values quite near to that required by Maxwell's law. It was thus shown that low temperature has the same effect as high frequency in annulling the abnormal dielectric values. The exact measurement of the dielectric constant of liquid oxygen, as well as its magnetic permeability, combined with the optical determination of the refrative index showed that liquid oxygen strictly obeys Maxwell's electro-optic law even at very low electric frequencies. In magnetic work the result of greatest value is the proof that magnetic susceptibility varies inversely as the absolute temperature. This shows that the magnetization of paramagnetic bodies is an affair of orientation of molecules, and it suggests that at the absolute zero all the feebly paramagnetic bodies will be strongly magnetic. The diamagnetism of bismuth was found to be increased at low temperatures. The magnetic moment of a steel magnet is temporarily increased by cooling in liquid air, but the increase seems to have reached a limit, because on further cooling to the temperature of liquid hydrogen hardly any further change was observed. The study of the thermo-electric relations of the metals at low temperatures resulted in a great extension of the well-known Tait Thermo-Electric Diagram. Tait found that the thermo-electric

power of the metals could be expressed by a linear function of the absolute temperature, but at the extreme range of temperature now under consideration this law was found not to hold generally; and, further, it appeared that many abrupt electric changes take place, which originate probably from specific molecular changes occurring in the metal. The thermo-electric neutral points of certain metals, such as lead and gold, which are located at or below the boiling point of hydrogen, have been found to be a convenient means of defining specific temperatures in this exceptional part of the thermo-metric scale.

The effect of cold upon the life of living organisms is a matter of great intrinsic interest, as well as of wide theoretical importance. Experiment indicates that moderately high temperatures are much more fatal, at least to the lower forms of life, than are exceedingly low ones. Professor McKendrick froze for an hour at a temperature of 182° C. samples of meat, milk, etc., in sealed tubes. When these were opened after being kept at blood heat for a few days their contents were found to be quite putrid. More recently some more elaborate tests were carried out at the Jenner Institute of Preventive Medicine on a series of typical bacteria. These were exposed to the temperature of liquid air for twenty hours, but their vitality was not affected, their functional activities remained unimpaired, and the cultures which they yielded were normal in every respect. The same result was obtained when liquid hydrogen was substituted for air. A similar persistence of life in seeds has been demonstrated even at the lowest temperatures. They were frozen for over a hundred hours in liquid air, at the instance of Messrs. Brown and Escombe, with no other result than to affect their protoplasm with a certain inertness, from which it recovered with warmth. Subsequently commercial samples of barley, pea, vegetable-marrow, and mustard seeds were literally steeped for six hours in liquid hydrogen at the Royal Institution, yet when they were sown by Sir W. T. Thiselton Dyer at Kew in the ordinary way the proportion in which germination occurred was no less than in the other batches of the same seeds which had suffered no abnormal treatment. Bacteria are minute vegetable cells, the standard of measurement for which is the "mikron." Yet it has been found possible to completely triturate these microscopic cells when the operation is carried out at the temperature of liquid air, the cells then being frozen into hard, breakable masses. The typhoid organism has been treated in this way and the cell plasma obtained for the purpose of studying its toxic and immunizing properties. It would hardly have been anticipated that liquid air should find such immediate application in biological research. A research by Professor Macfadyen,[a] just concluded, has shown that many varieties

[a] Note by author, April 16, 1903. This important paper has recently appeared in the Proceedings of the Royal Society.

of microorganisms can be exposed to the temperature of liquid air for a period of six months without any appreciable loss of vitality, although at such a temperature the ordinary chemical processes of the cell must cease. At such a temperature the cells can not be said to be either alive or dead in the ordinary acceptation of these words. It is a new and hitherto unobtained condition of living matter—a third state. A final instance of the application of the above methods may be given. Certain species of bacteria during the course of their vital processes are capable of emitting light. If, however, the cells be broken up at the temperature of liquid air, and the crushed contents brought to the ordinary temperature, the luminosity function is found to have disappeared. This points to the luminosity not being due to the action of a ferment—a "Luciferase"—but as being essentially bound up with the vital processes of the cells and dependent for its production on the intact organization of the cell. These attempts to study by frigorific methods the physiology of the cell have already yielded valuable and encouraging results, and it is to be hoped that this line of investigation will continue to be vigorously prosecuted at the Jenner Institute.

And now, to conclude an address which must have sorely taxed your patience, I may remind you that I commenced by referring to the plaint of Elizabethan science that cold was not a natural available product. In the course of a long struggle with nature, man, by the application of intelligent and steady industry, has acquired a control over this agency which enables him to produce it at will and with almost any degree of intensity short of a limit defined by the very nature of things. But the success in working what appears at first sight to be a quarry of research that would soon suffer exhaustion, has only brought him to the threshhold of new labyrinths, the entanglements of which frustrate with a seemingly invulnerable complexity the hopes of further progress. In a legitimate sense all genuine scientific workers feel that they are "the inheritors of unfulfilled renown." The battlefields of science are the centers of a perpetual warfare, in which there is no hope of final victory, although partial conquest is ever triumphantly encouraging the continuance of the disciplined and strenuous attack on the seemingly impregnable fortress of nature. To serve in the scientific army, to have shown some initiative, and to be rewarded by the consciousness that in the eyes of his comrades he bears the accredited accolade of successful endeavor, is enough to satisfy the legitimate ambition of every earnest student of nature. The real warranty that the march of progress in the future will be as glorious as in the past lies in the perpetual reenforcement of the scientific ranks by recruits animated by such a spirit and proud to obtain such a reward.

EXPERIMENTAL PHONETICS.[a]

By Prof. JOHN G. MCKENDRICK, F. R. S.[b]

The movements of the organs of voice and speech are so complicated as to require for their elucidation the application of many methods of research. When one speaks there are movements of the lips, tongue, soft palate, and larynx, and sometimes movements of the muscles of expression. Then, again, there are special characteristics about vowel sounds which apparently distinguish these from the sounds of musical instruments. Thus questions arise as to the true nature of vowel sounds and as to what is the physical constitution of a word of several syllables. It has also been suggested that language might be recorded, not by letters or syllables, but by signs or symbols which would indicate what had to be done by the vocal and articulating organs for the production of any given sound. There might thus be a physiological method of expressing speech by a series of alphabetical symbols for sounds varying in pitch, intensity, and quality. It will be seen that experimental phonetics constitutes a wide field of research, not only of great scientific interest, but also one having practical aspects not at first apparent. From the nature of the investigation, also, the problems seem to be specially suited for the application of the graphic method of research.

In 1875 an investigation was carried out by Havet and Rosapelly[c] in the laboratory of Professor Marey, in Paris, in which the pressure

[a] Reprinted by permission of the author and the publisher from Nature, London, No. 1678, vol. 65, Dec. 26, 1901.

[b] Read before the Section of Physiology at the meeting of the British Association in Glasgow, September 13. References: Die Phonetische Literatur von 1876–1895, by Hermann Breymann (Leipzig, 1897); The Articulation of Speech Sounds by Analphabetic Symbols, by Otto Jespersen (Marburg, 1889); L'Inscription des Phénomènes Phonétique, by M. J. Marey (Revue Générale des Sciences, 15 et 30 Juin, 1898); Studies from the Yale Psychological Laboratory, by E. W. Scripture (1899); Théorie de la Formation des Voyelles, by Marage (Paris, prix Barbier, 1900); La Parole d'après le Tracé du Phonographe, by H. Marichelle (Paris, 1897); On Vowel Sounds, by J. G. McKendrick and A. A. Gray; Schäfer's Text-Book of Physiology, vol. ii, p. 1206, in which the recent bibliography is given in delail.

[c] Rosapelly: Inscription des Movements Phonétiques, in Travaux de Laboratoire de M. Marey (Paris, 1875).

of the air in the nose, the movements of the lips, and the vibrations of the larynx were simultaneously recorded. Special contrivances were devised for transmitting these movements to three of Marey's tambours, so arranged as to record on the surface of a blackened drum three superposed curves which indicated the order of succession, duration, and intensity of the movements of the organs. The emission of

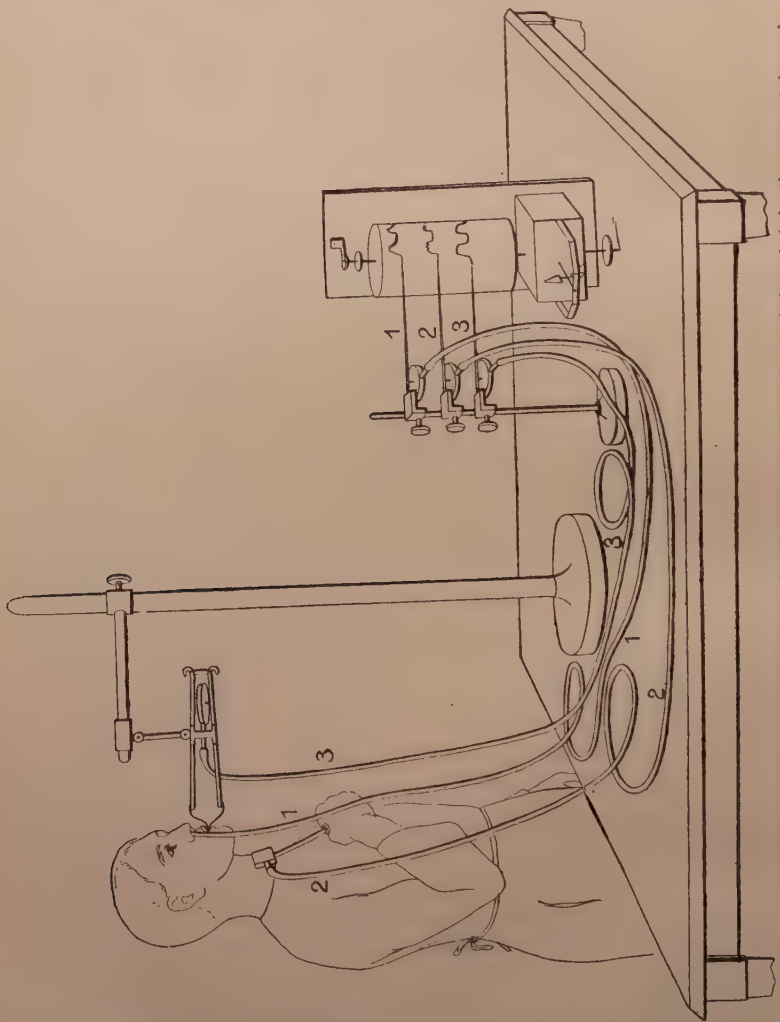


FIG. 1.—A method for recording simultaneously the different acts of speech: Emission of air by the nares (tube and lever, 1), vibrations of the larynx (2), and movements of the lips (3).

air from the nostril indicated movements of the soft palate, and these were signaled by an india-rubber tube introduced into one nostril, while the other end was connected with a tambour, as in fig. 1. A small electromagnetic apparatus was placed over the larynx, and by making and breaking a current the vibrations of the larynx were transmitted to another tambour. The movements of the lips were

recorded by a device which caused the pressures to act on a third tambour, as is shown in the figure.

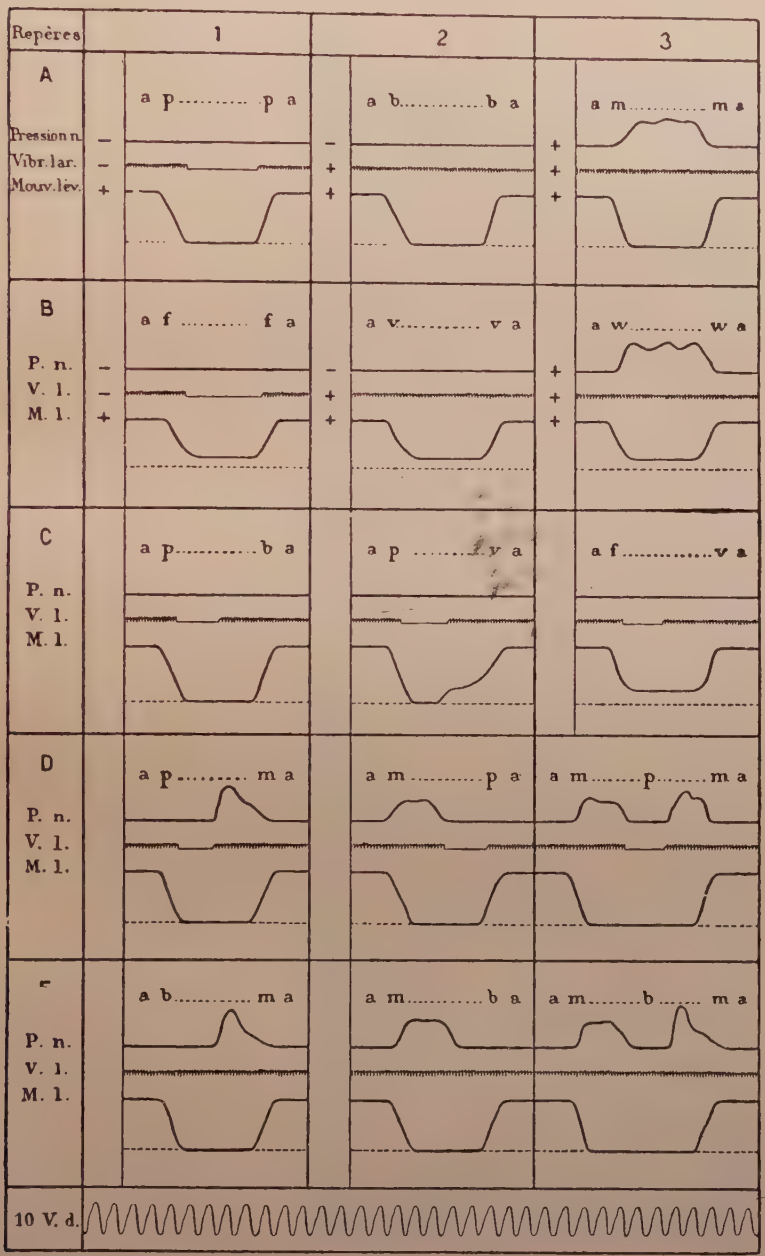


FIG. 2.—Tracings of nasal, laryngeal, and labial movements in the pronunciation of various phones.

This method was found to give characteristic tracings for the sounds of consonants, but the records obtained from vowel sounds were all

very much alike. It was also observed that if one of the tambours did not act, say the one recording the vibrations of the larynx, it was difficult to distinguish the tracings of certain consonantal sounds. Thus *p* resembled *b*, so far as the movements of the lips and the nasal pressures were concerned, but with *b* there is a vibration of the larynx as well, while this is absent in the tracing of *p*. In fig. 2 is shown a table in which is depicted the traces obtained on uttering the vowel *a* either before or after various consonants. In these tracings, P *n* indicates nasal pressure, V *l* vibrations of the larynx, and M *l* movements of the mouth. Five examples are given of combinations of A with consonants. If there is no emission of air from the nostrils, the line P *n* is unbroken and horizontal, but if there is emission, then an elevation is seen as in A 3 with *a m*, or *m a*. A sinuous line in V *l* shows that the larynx vibrates, but if there is no laryngeal vibration the line is straight. It will be observed that in some cases the larynx vibrates throughout all the experiment, as in A 2, while in others there is an interruption, as in B 1. The movements of the lips in M *l* show a curve which varies in amplitude and duration according as the lips are more or less approximated and according to the duration of complete or partial occlusion.



FIG. 3.—Change of expression during speech. Chronophotography. Ten images per second.

These syllabic sounds may be termed phones. This research is an excellent example of the application of the graphic method to the movements of speech. The method has been much developed by Rousselot[a] in the Collège de France, where there now exists a special laboratory for research in phonetics.

Professor Marey, whose earlier researches are well known to have had much to do with the development of the kinematograph, employed, so long ago as 1888, chronophotography to catch those evanescent changes of the countenance the sum total of which give expression to the face in speech. In fig. 3 are seen the changes of expression in

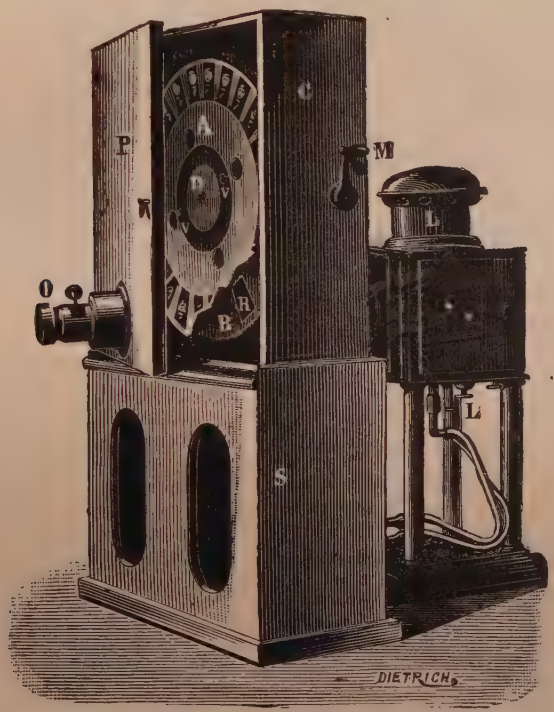


FIG. 4.—Photophone of Demeny. A, glass disc carrying the pictures; B, another disc, perforated; L electric lamp; O, lens.

a woman's face in speaking during a period of half a second. If these successive pictures are projected by a lantern (fig. 4) there is an animated face on the screen. In this way Marichelle succeeds in placing before the eyes of deaf mutes images of the movements of speech which they are urged to imitate.

It is interesting, in the next place, to trace the efforts that have been made by physicists and physiologists to record the pressures produced by sound waves, and more especially those of the voice.

[a] Rousselot: Principes de Phonétique Expérimentale (Paris, 1897).

In 1858 Leon Scott invented the phonautograph seen in fig. 5. In its first form this instrument gave very imperfect tracings, but it is of great interest as being the forerunner of the phonograph. It was much improved by Rudolph König, of Paris. Donders[a] in 1868

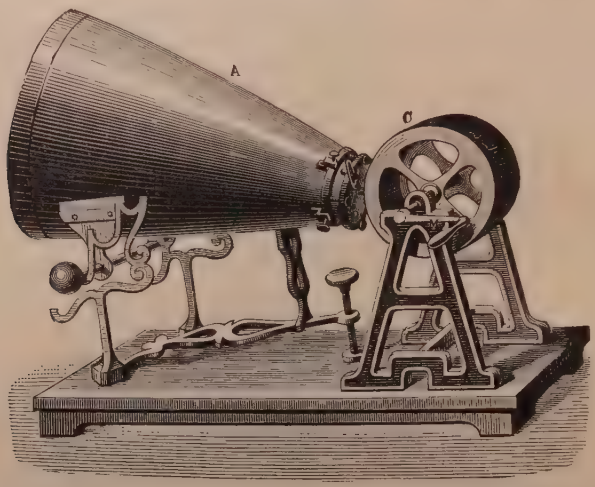


FIG. 5.—Phonautograph of Leon Scott. A, paraboloid resonator, closed at one end by a membrane, to which a light lever is attached. C is a drum covered with smoked paper on which the lever traces a curve. As C rotates it moves from right to left.

was the first to use the instrument in the investigation of vowel tone. Then came the logograph of Barlow[b] in 1876, which was a membrane furnished with a rigid, but light, lever, having its fulcrum at the edge of the membrane, while the power was applied from the center of the membrane. This gave more accurate tracings—that is

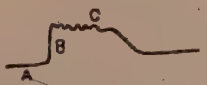


FIG. 6.—Tracings of the sound *b e*.

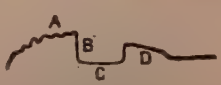


FIG. 7.—The sound *e b*.

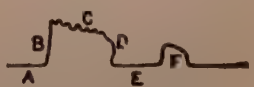


FIG. 8.—The sound *b e b*.

to say, tracings that indicated with more precision the variations of pressure on the membrane. Examples are given in figs. 6, 7, and 8.

In fig. 6, at A, the membrane is at rest; at B the lever is raised by the sudden emission of the consonant *b*, and this is succeeded by the prolonged vibration of the vowel *e*. Fig. 7 gives a different picture

[a] Donders: Zur Klangfarbe der Vocale (Ann. der Physik und Chemie, 1868).

[b] Barlow: On the Articulation of the Human Voice, as Illustrated by the Logograph (Trans. Roy. Soc. 1876).

for *e b;* A is the vowel *e;* B the closure of the lips at the beginning of the consonant; this closure lasts during C, and D is due to the elasticity of the air compressed in the mouth. In fig. 8, *b e b*, we find the elements of figs. 6 and 7. By the logograph the consonantal sounds were alone depicted, the records of the vowels being very imperfect.

There was still a demand for a recorder of greater accuracy. Schneebeli[a] in 1878 devised an instrument seen in fig. 9. From the center of a parchment membrane arises a thin, but rigid, steel plate; attached to this, near the point, is another steel plate passing horizontally from the edge of the metallic ring carrying the membrane. The movements of the membrane are five times increased in amplitude, while the extreme lightness of the lever reduces to a minimum the effects due to inertia. Examples of curves obtained by this method are shown in fig. 10.

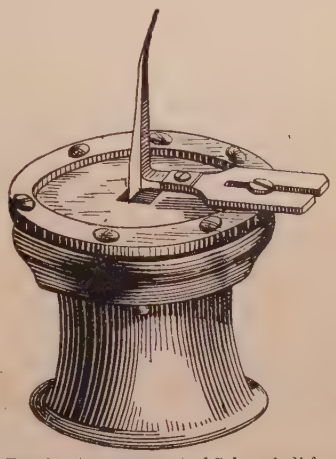


FIG. 9.—Arrangement of Schneebeli for recording movements of a membrane.

A very sensitive apparatus, termed the Sprachzeichner, has also been introduced by Hensen[b] for recording the delicate vibrations of a membrane. It will be readily understood by referring to figs. 11, 12, and 13. Valuable observations have been made with the aid of this instrument by Wendeler[c] on consonant sounds, by Martens[d] on vowels and diphthongs, and by Pipping[e] on vowels.

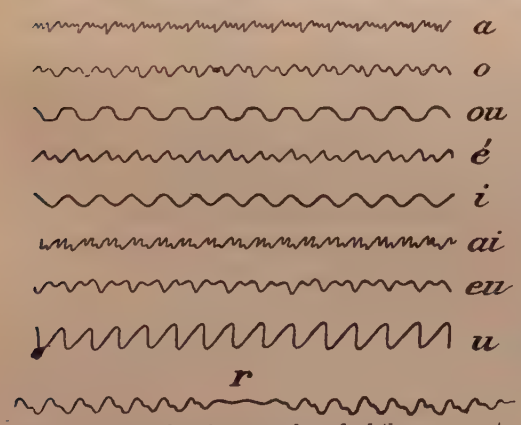


FIG. 10.—Curves of various vowels and of the consonant *r* recorded by the apparatus of Schneebeli.

Such are some of the mechanical contrivances that have been devised for recording the movements of a membrane. None

[a] Société des Sciénces Naturelles de Neuchâtel, 25 Avril et 20 Novembre, 1878.

[b] Hensen: Ueber der Schrift von Schallbewegungen (Zeits. für Biologie, 1887).

[c] Wendeler: Ein Versuch über die Schallbewegungen einiger Konsonanten (Zeits. für Biologie, 1886).

[d] Martens: Ueber des Verhalten von Vocalen und Diphtongen in Zesprochenen Worten (Zeits. für Biologie, 1889).

[e] Pipping: Zur Klangfarbe der Gesungen Vocale (Zeits. für Biologie, 1890); Ueber die Theorie der Vocale (Arta Societatis Scientiarum Helsingfors, 1894).

are free from error, however delicate they may seem to be, owing to the inertia of the parts, and consequently other arrangements were demanded. In 1862[a] Rudolph König introduced his well-known method of showing the movements of membranes by manometric flames. The apparatus is now so well known as to require no detailed

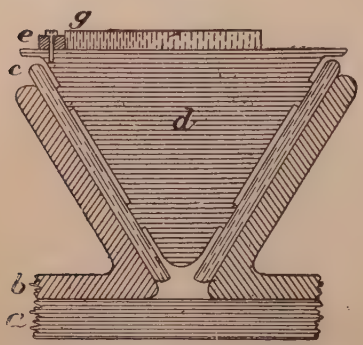


FIG. 11.—Apparatus of Hensen. *d*, Wooden prism; *c*, glass; *g*, smoked glass kept in its place by a screw clamp, *e*; *a*, *b*, supports.

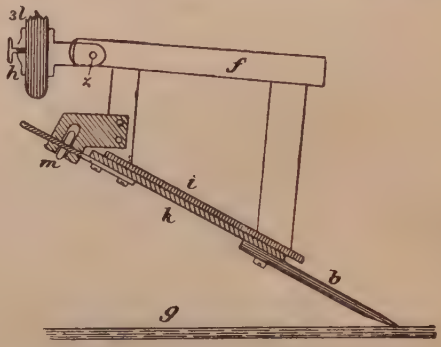


FIG. 12.—The recording portion of the Sprachzeichner of Hensen. *f*, *i*, frame having a joint, *z*; *b*, wooden point; *g*, smoked glass.

description. Gas is led by a tube into a small capsule of wood, the cavity of which is divided by a thin membrane (fig. 14, A). The gas passes into the right half of the cavity and escapes into a small burner, where it is lit. If sound waves are diverted by a small conical resonator into the left half of the capsule, the membranous partition vibrates, there are alternations of compression and of rarefaction in the gas on the right side, and the flame is agitated, moving upward and downward with each vibration. The method of Wheatstone of dissociating the flames by a rotating mirror is then employed, and a sinuous ribbon is seen in the mirror. The ribbon is cut vertically into teeth, some larger, some smaller. The larger, less frequent, correspond to the fundamental tone of the sound, the smaller to the harmonics that enter into the composition of the compound tone on which the quality of the vowel depends.

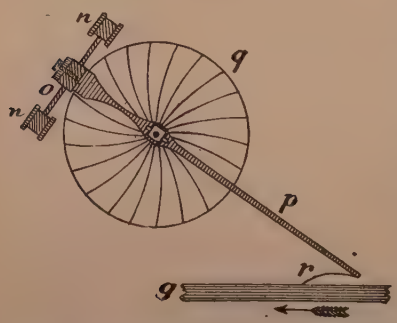


FIG. 13.—Writing portion of Hensen's apparatus. *n*, *n*, weights supporting an axis *o*, carrying marker *p*, with a point *r*; *q*, a disc communicating to the marker *p* the movements of the membrane; *g*, smoked glass plate.

These flame pictures are only seen for an instant, and many efforts have been made to fix them by photographic methods. This was first

[a] König: Quelques Experiences d'Acoustique (Paris, 1882).

attempted by Gerhardt[a] in 1877. He used the flame of cyanogen, and the somewhat poor result is shown in fig. 16.

Doumer[b] obtained a brilliant flame by burning carburetted hydrogen in oxgen, and he also introduced into such researches a chronophotographic method by reproducing the images of a flame acted on by a tuning fork of known pitch. Marage,[c] to whose researches we shall afterwards refer, feeds the capsule with actylene, and thus obtains a luminous flame. The result of such an arrangement is shown in fig. 17.

It will be observed that all manometric flames seen in a rotating mirror are inclined, as their composition is due to a horizontal and vertical translation, and the faster the mirror is rotated the more they are inclined.

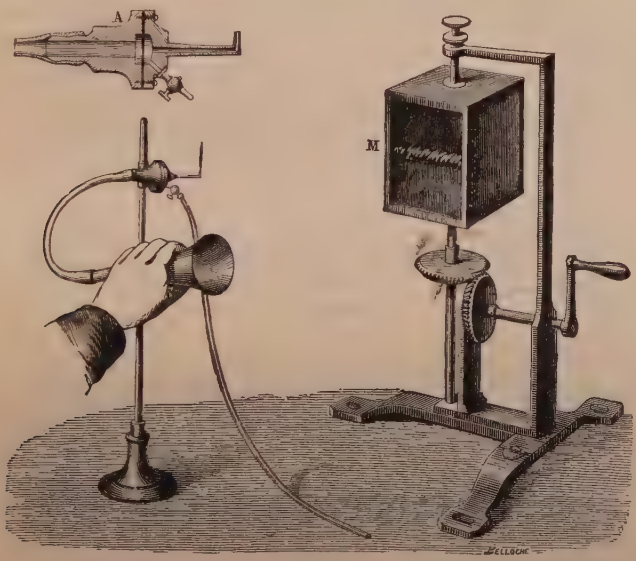


FIG. 14.—König's apparatus. A Manometric capsule; M, rotating mirror.

Efforts have also been made to analyze sounds by photographing a ray of light reflected from a vibrating mirror. Long ago, but without photography, Czermak applied this method to the phenomenon of the pulse, and in 1879 Blake[d] devised a mirror for thus recording speech. He used a small metallic plate, in the center of which was a small hook which is attached to a very light mirror delicately swung on two pivots, *c*, *c*, fig. 18. A ray of light is thrown on the mirror by a convex lens; after reflection it again traverses a lens and falls on a photographic plate in movement. Sharp, well-defined images are thus obtained (fig. 19).

[a] Stein: Die Licht im dienste wissenschaftlicher Forschung (Leipzig, 1877).

[b] Doumer: C. R. de l'Académie des Sciences, 1886.

[c] Marage: Étude des Cornet Acoustiques par la Photographie des Flammes Manometriques de König (1897).

[d] Blake: American Journal of Science and Art, 1878; Journal de Physique, 1879.

The amplitudes of the tracings thus obtained from the tones of the voice were 25 millimeters (1 inch), while those of the mirror were only 0.125 millimeter (one two-hundredth inch).



FIG. 15.—Examples of flame pictures obtained by König's system of a monometric capsule adapted to two organ pipes. The figures to the left indicate the ratio of the vibrations of the two tones forming the compound tone.

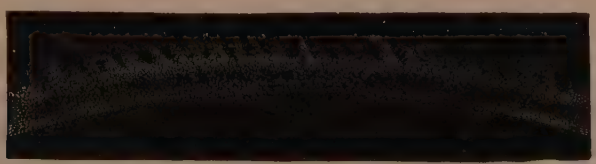


FIG. 16.—Vibrating flame of cyanogen photographed by Gerhardt.

Rigollot and Chavanon,[a] in 1883, constructed a mirror apparatus shown in fig. 20, and Hermann,[b] in 1889, used a somewhat similar arrangement, the tracings of which are given in fig. 21.

[a] Journal de Physique, 1883. [b] Hermann: Pflüger's Archiv., 1889.

An ideal method for recording vibrations was devised by Rops in 1893, ideal inasmuch as it does not use any vibrating membrane or lever or anything having inertia. A diagram is given in fig. 22

It is based on the principle of photographing the effects of interferences of light waves. Rays from a luminous source A pass through the lenses $q\ q$ so as to become parallel. They then pass through a slit d and a hole in a diaphragm b, and they are focused by a lens l (of 15 centimeters focal length) so as to fall on a glass plate S_1. The ray divides into two, a_1 and a_2, and they run parallel, the ray a_1 passing through the air while a_2 passes along a tube g (15 centimeters in length), the ends of which are closed by the glass plates h and h_1. A few centimeters from the tube there is a resonator, i, into which the vowels are sung, thus causing condensations and rarefactions of the air, disturbing the ray $h\ h_1$ while the ray passing through the tube g is unaffected. The two rays are again united by S_1; they then pass through an objective c and a lens z to a slit in a screen so as to fall on sensitive paper on the drum T. A diaphragm b cuts off secondary reflections. Thus beautiful images are formed corresponding to the vowels spoken or chanted into the resonator.



Fig. 17.—Photograph of manometric flames of acetylene showing vibrations of vowel o. Above are the images of chronographic flames—54 double vibrations per second.

The invention of the tin-foil phonograph by Edison in 1877 and the improvement of the instrument by the labors of Edison, Graham Bell, and others in more recent years has made it possible to investigate phonetic phenomena with the aid of this instrument. In 1878 Fleeming Jenkin and Ewing[a] devised a method of recording curves from the imprints on the tin-foil covering the drum of the phonograph, and these curves were submitted to harmonic analysis. This was also attempted by

[a] Fleeming Jenkin and Ewing: On the Harmonic Analysis of certain Vowel Sounds (Trans. Roy. Soc. Edin., vol. xxviii, p. 745).

A. M. Mayer[a] in the same year. The subject was taken up by Hermann[b] about 1890, and he obtained valuable tracings by using the wax-cylinder phonograph. He succeeded in obtaining photographs of the curves on the wax cylinder, a beam of light reflected from a small mirror attached to the vibrating disk of the phonograph being allowed to fall on a sensitive plate while the phonograph was slowly traveling. In 1891 Boeke[c] measured with great accuracy the dimensions of the marks on the wax cylinder, and from these constructed the corresponding curves. This method has also been adopted by Marichelle.[d] McKendrick[e] in 1895 photographed the marks on the wax cylinder of the phonograph, and in 1896 he devised a recorder for enlarging the curves on the well-known principle of the syphon recorder. In 1899 Scripture,[f] of Yale, investigated vowel sounds with the aid of the gramophone. He transcribed, by an ingenious mechanical device, the marks on the gramophone disk into the forms of curves and made a minute analysis. Lastly, Marage,[g] in a series of masterly papers, reinvestigated the whole subject of vowel tones with the aid of a chrono-photographic method and a special form of syren invented by himself.

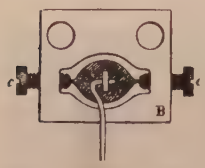


FIG. 18.—Blake's mirror.

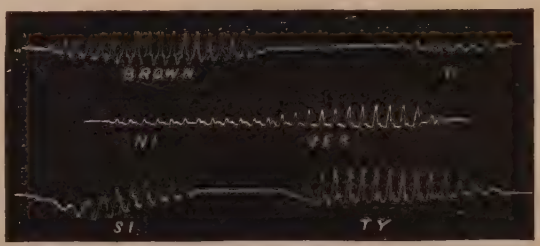


FIG. 19.—Photographic tracings obtained by Blake's method.

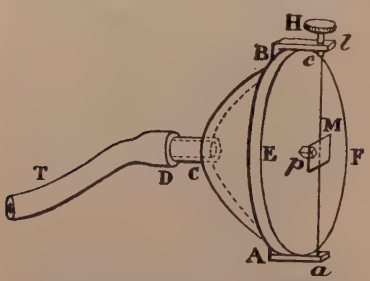


FIG. 20.—Palmoptic capsule of Rigollot and Chavanon (παλμικος, pertaining to vibrations). E F, collodion membrane; M, mirror carried by a wire a c, stretched between supports A and B, and regulated by the screw H; p, small cube of india rubber resting on center of membrane; T, tube.

The various experimental methods we have described have been chiefly directed to an examination of the nature of vowel sounds. What

[a] Mayer: Journal de Physique, 1878.

[b] A full bibliographical reference to Hermann's papers is given in Schäfer's Text-Book of Physiology, vol. ii, p. 1222.

[c] Boeke: Microscopische Phonogrammstudien (Archiv. f. d. ges. Physiol., Bonn, Bd. i, S. 297; also Proc. Roy. Soc. Edin., 1898).

[d] Marichelle: La Parole d'après le Tracé du Phonographe (1897).

[e] McKendrick: Trans. Roy. Soc. Edin., vol. xxxviii, pt. iv; Proc. Roy. Soc. Edin., 1896–97; also Sound Waves as Revealed by the Phonograph (London, 1897).

[f] Scripture: Studies from the Yale Psychological Laboratory (1899).

[g] Marage: Comment parlent les Phonographes; Les Exercises Acoustiques chez Les Sourds Muets; Rôle de la chaîne des osselets dans l'Audition; and Théorie de la Formation des Voyelles (from 1897 onward).

is it that gives the peculiar quality to the sound of a vowel? How is it that we can, by the ear, identify the sound of any vowel, whether it be spoken or sung? How is it that if we sing a vowel on the notes of a scale we can still identify the vowel whatever may be the pitch of the note on which it is sung? The scientific investigation of the nature of vowels begins with Willis,[a] who, in 1829, imitated the larynx by means of a reed, above which he placed a resonator, tuned to one of the harmonics of the reed. He also imitated vowel tones by holding an elastic spring against the edge of a toothed wheel, and he placed the vowels in the following order—*ou*, *o*, *a*, *e*, and *i*. In each case a compound tone was produced which retained the same pitch so long as the wheel revolved at the same rate. By keeping the wheel revolving at a uniform rate, and at the same time changing the length of the spring which was allowed to vibrate, Willis found that the qualities of various vowels were imitated with considerable distinctness. In 1837 Wheatstone,[b] in a criticism of Willis, made some important suggestions. In 1854 Grassmann[c] announced a theory as follows: The vocal chords excite the resonances of the cavity of the mouth; the tonality changes with the degree of opening of the mouth by the development of some of the harmonics of the fundamental tone emitted by the larynx. According to this view the buccal cavity adds by its resonance certain harmonics to the fundamental laryngeal sound. Grassmann classified the vowels according to the number of harmonics which they contained in the following table:

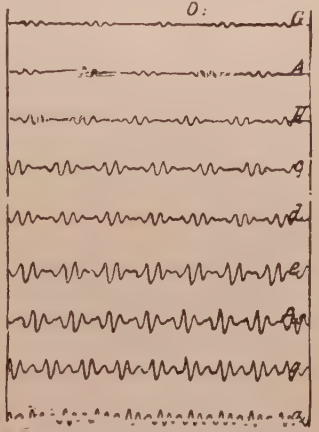


FIG. 21.—Tracings obtained by Hermann of vowel o.

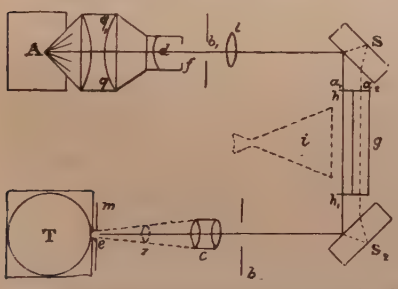
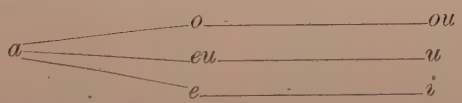


FIG. 22.—Rops's apparatus for the analysis of vowel-tones.



[a] Willis: Cambridge, Phil. Trans., 1829, vol. iii, p. 231; also Ann. d. Phys. u. chem., Leipzig, Bd. xxiv, p. 397.

[b] Wheatstone, Westminster Review, October, 1837.

[c] Grassmann: Über die physik. Natur des Sprachleute, 1877; he had, however, in 1854, enunciated his theory in Uebersicht der Akustik u. der niedem Optik.

In sounding *a* the mouth is widely opened and the fundamental and eight harmonics are produced; in the third series, on the contrary, there is only one harmonic sounded, which is more and more acute as we pronounce the vowels in the order *ou*, *u*, and *i*. The vowels of the second series, *o*, *eu*, and *e*, are transitional between the first and the third. Thus we pass from *a* to *ou* by *o*, from *a* to *u* by *eu*, and from *a* to *i* by *e*.

Donders[a] showed that the cavity of the mouth, as arranged for the giving forth of a vowel, was tuned as a resonator for a tone of a certain pitch, and that different pitches corresponded to the forms of the cavity for the different vowels. This he discovered by the peculiar noise produced in the mouth when the different vowels are whispered. The cavity of the mouth is then blown like an organ pipe and by its resonance reinforces the corresponding partials in the rushing wind-like noise. Then the question was taken up by Helmholtz.[b] He attacked it both by analysis and by synthesis. He analyzed the vowel tones by his well-known resonators, aided by his own singularly acute ear, and he attempted to combine, by means of tuning forks, the tones which he thought existed in a vowel, so as to reproduce the sound of the vowel. In the latter part of the investigation he was by no means successful. These investigations led Helmholtz to put forward in succession two theories as to the formation of vowels. The first was that, as in all musical instruments, the quality or timbre of the vowel depends on the fundamental tone, reinforced by certain partials or overtones, of which a number are produced by the vocal cords along with the fundamental tone, the reinforcement depending on the resonance of the cavities above the vocal cords. This theory was upset by the use of the phonograph. If a vowel is sung to the phonograph while the cylinder is traveling at a certain speed, the vowel tone will be reproduced with exactly the same quality if the cylinder is driven at the same speed; but if it is driven faster, then the quality of the vowel will be changed, so much so as to be scarcely recognizable. M. Marey narrates that Donders and he first made this observation when it so happened that the two savants were present in Paris at a public demonstration of the phonograph soon after its invention. Donders sang the vowel tones to the instrument, and then asked the operator to vary the speed of the cylinder during reproduction. Then the vowel *a* became *o*, and *e* became *ou*. Thus while the phonograph reproduces in a wonderful way the tones of musical instruments without change of quality, it can not transpose vowel tones without altering their character. This special character or quality can not, then,

[a] Donders: De physiologie der Spraakklanken (1870).

[b] Helmholtz: Ueber de Vokale. Archiv. f. d. Holland. Beitr. 2, Nat. u. Heilk. (Utrecht, 1857). See other references given in Schäfer's Text-Book, vol. ii, p. 1217 (footnote).

depend on the overtones reinforced by the oral cavities being simple multiples of the fundamental tone, and Helmholtz's first theory had to be abandoned.

This led Helmholtz to advance a second theory, as follows: Each vowel is characterized by a certain harmonic or partial tone, of constant pitch, whatever may be the pitch of the note on which the vowel is sung or spoken. Attempts were then made, notably by Hemholtz and König, to fix the pitch of the characteristic partial tone or vocable, and there appeared to be considerable differences in the results of the two distinguished observers, differences amounting to as much, in some cases, as three semitones.

The next step was, as has already been explained, to transcribe the marks on the wax cylinder of the phonograph, made on singing or speaking a vowel, into sinuous curves and to subject these to harmonic analysis. It is not difficult, in comparatively simple cases, to obtain a curve which is the algebraic sum of the ordinates of several sinussoidal curves, but it is not so easy to do the reverse operation, namely, to analyze the curves. Fleeming Jenkin, and Ewing, afterwards Schneebeli, Hensen, Pipping, and Hermann, have done this in accordance with the theorem of Fourier and the law of Ohm. In particular, Hermann, by a beautiful and ingenious method, has analyzed the curves obtained by his photographic device, and has modified the theory of Helmholtz. His statement is that the oral cavity produces independently a harmonic or partial tone which has no definite relation to the fundamental tone emitted by the larynx. A vowel, according to him, is a special acoustic phenomenon, depending on the intermittent production of a special partial, or "formant," or "characteristique." The pitch of the "formant" may vary a little without altering the character of the vowel. For *a*, for example, the "formant" may vary from fa_4 to la_4, even in the same person. He has also attempted, but not with complete success, to reproduce the vowel tones by synthesis.

There are thus three theories: (1) The first of Helmholtz, now abandoned, that the pitch of the partials is represented by simple multiples of the vibration periods of the fundamental; (2) the second of Helmholtz, that the pitch of the characteristic partial is always fixed, but has a definite relation to the pitch of the fundamental; and (3) that of Hermann, that the pitch of the characteristic partial or "formant" is not absolutely fixed.

The difficulty of harmonizing these theories has stimulated the zeal of many workers, and in particular Dr. Marage[a] has been remarkably successful in his researches into the nature of vowels. He first of all criticizes the second theory of Helmholtz, pointing out that the failure to reproduce the vowels by synthesis is strongly against it. Thus while,

[a] Marage: Théorie de la Formation des Voyelles, op. cit.

by tuning forks, the pitch of which is that of the partials of the fundamental tone, *ou*, *o*, and *a* may be badly reproduced, it has been found impossible to reproduce E and I. He then objects to the theory of Hermann, namely, that the vowel is an oral intermittent and oscillating tone; first, that the method of recording the vowel on the wax cylinder of the phonograph causes grave errors, because the mouthpiece, tube, air chamber, and vibrating disk all profoundly modify the vowel; second, that the method of analysis by Fourier's theorem assumes that the vowel curves are constituted by superposed simple curves, which is precisely the question at issue, and therefore the argument is a petitio principii; and third, that the data obtained by his method have not enabled Hermann to reconstruct the vowels with greater success than Helmholtz. Marage then enters upon his own method, which consists essentially of using a special apparatus constructed on König's principle of manometric flames, but so simple as to be practically free from sources of error; that is to say, there is no mouthpiece, tube, or lever. The pictures of the flames were produced photographically by feeding the flame with acetylene gas, and chronophotometrical records were taken with each experiment. He then finds that the flame pictures of I, U, and OU show one flame, E, EU, and O two flames, and A three flames. So that the classification of the vowels by flames is exactly that of Grassmann. Each vowel, when all errors have thus been got rid of by simplifying the apparatus, always gives the same picture for any given note. The picture is that of a continuous periodic curve, and the number of periods in a second corresponds to the laryngeal note, while the form of the period characterizes the vowel. With the same vowel the period changes with the note. When the note is near the pitch of ordinary speech the period varies very little. This is not so when the vowel is sung; the period then disappears until there is only the laryngeal note. Marage has also by synthesis reproduced the vowels with remarkable success. His first experiments with resonators were not quite satisfactory; he could reproduce OU, O, and A, but not E and I. He ascertained, however, that to reproduce A the resonator must be tuned to the third harmonic or partial of the note on which A was sung; that to reproduce E, EU, and O the best result was obtained when the resonator gave the second partial; and I, U, and OU were imitated (but not successfully) when the resonator was in unison with the laryngeal tone.

Marage finally devised a syren rotated by an electric motor and consisting of a disk having in it a triangular window representing the glottis. The air is driven under pressure through this aperture and then falls on another disk having windows cut out of it in groups according to the nature of the vowel to be synthetically reproduced. Thus the disk for A has four groups, each group consisting of three triangular slit-like windows; for O and E the disk shows five groups,

each consisting of two slits; and for I and OU there are many slits, without these being arranged in groups. The slits are very large for O and narrow for E, and large for OU and narrow for I. He then molded a series of casts of the interior of the oral and pharyngeal cavities of a human subject, as these were adapted for the singing of the different vowels, and from them constructed masks or headpieces which could be placed over the syren so that the air escaping from it passed through the cavities of the mask. He found that if air was driven through the masks under a pressure of only 7 centimeters of water the timbre of the corresponding vowel was at once perceived, as in whispering. Marage's view is that to form a vowel the true vocal cords vibrate in a horizontal plane, in such a way as to influence by their greater or less degree of approximation the escape of air.

If the air escapes in three little puffs as it were (the cords vibrating during each puff a number of times equal to the pitch of the note on which the vowel is spoken or sung), so that there are intervals between the groups of puffs, then the vowel A is the result. The oral resonater is in unison with the sum of the vibrations and the vowel is emitted. If the resonater (either artificial or the oral cavity, as in life) is turned to the third harmonic of this note, then the vowel A is modified; the same applies to E and O, which have the second harmonic, and in passing from the one vowel to the other it is sufficient to change the aperature of the glottic opening. Thus for A, if the fundamental note is n, the oral resonator must be tuned to $3n$; for E and O, if the fundamental is n', the oral resonator gives $2n'$; and for I and OU the resonater is in unison. If this is not so, then the quality of the vowel is much altered. Thus if the syren gives A, and the plate used is that for OU, then the sound is A modified. This agrees with the experience of teachers of singing, who hold that a badly sung vowel is a vowel sound emitted into a cavity adjusted for another vowel. Marage has also found that when the sounds of his syren, aided by the masks, are examined by the manometric method, the flame pictures appear as they may be expected to do—that is, groups of three flames for A, of two for E, EU, and O, and of one for I, U, and OU. Vowels then, according to him, are due to an intermittent aëro-laryngeal vibration, strengthened by the oral cavity and producing OU, O, A, E, and I, when it is in unison with the sum of the vibrations; transformed by it, and giving origin to other vowels, when there is no unison; and the number of intermittences gives the fundamental note on which the vowel is emitted. If the oral cavity acts alone, the vowel is whispered; if the larynx acts alone, the vowel is sung; and if the two act, the vowel is spoken. Marage has applied his method with much success in testing the ear and in the treatment of mutes who are not absolutely deaf. His memoir is characterized by great simplicity and at the same time by thoroughness.

But the study of vowels is not the only result of recent research in phonetics. The analysis of consonantal sounds is now being carried out by various workers, such as Pipping, Scripture, and Lloyd. Meyer, in Hermann's laboratory, has investigated the pitch of words, sentences, and syllables in speech. This has also been studied by phonographic tracings by Marichelle. The whole subject has also a practical bearing, as the knowledge acquired enables the teacher of deaf mutes so to instruct his pupils in the use of their organs as to avoid the dreary monotone of those who learn to speak by watching only the movements of the lips.

It only remains to notice the remarkable monograph of Jespersen. This is an attempt to aid the study of phonetics by the use of a scientific nomenclature to express sounds, so that just as the chemist represents by letters and figures the nature of a chemical substance of complex constitution so the student of phonetics may be able to express the sounds of words by symbols. The visible-speech system of Melville-Bell consisted of symbols which expressed more or less accurately the physiological movements to be made, or the position to be assumed during the pronunciation of a given sound; but the symbols of Jespersen are letters and figures. The letters or figures, however, to be useful must have a physiological meaning. Strictly speaking, the symbols denote, not sounds, but the elements of sounds. Thus so simple a sound as *m* is physiologically the result of (*a*) lips shut; (*b*) point of tongue resting in the bottom of the mouth; (*c*) surface of tongue not raised toward the palate; (*d*) nasal passage open; (*e*) vocal cords vibrate, and (*f*) air expelled from lungs. The attempt of Jespersen may be called an alphabetic system of writing, symbolizing, not sounds, but the elements of sounds. At present it is severely technical, but it seems to "provide a means of writing down and describing phonetic minutiæ in a comparatively easy and unambiguous manner." It will do for the phonetician what symbolism does for the mineralogist. It is a kind of algebra for speech sounds.

In advocating the establishment of a photographic museum, to be a visual register of the past, Janssen recently wrote as follows: "Photography registers the chain of phenomena during time, just as writing registers the thoughts of men during the ages. Photography is to sight what writing is to thought. If there is any difference, it is to the advantage of photography. Writing is subject to conventionalities from which photography is free; writing employs a particular language, while photography speaks the universal language."

But if there is to be a museum of photographs, appealing to the sense of sight, why should we not have a museum of sounds, in the shape of phonograph records, appealing to the sense of hearing? How little can we tell from written characters the exact sounds of

ancient Sanskrit, or how Demosthenes spoke in Greek or Cicero in Latin? Would it not now be interesting to hear the exact accent of old English, or the Scotch of the fifteenth century? All dialects should be carefully registered and put aside for future consultation, and thus we would do for the ear what we do for the eye. No doubt such a collection of phonographic records would help onward the science of language.

WIRELESS TELEGRAPHY—ITS PAST AND PRESENT STATUS AND ITS PROSPECTS.[a]

By William Maver, Jr.[b]

Long before the dawn of the Christian era wireless methods of communicating intelligence to a distance were employed—not electric telegraphs as the term is generally understood, it is true, but wireless they certainly were, and perhaps as this article proceeds it will not be difficult to perceive a close relationship, as regards the nature of the communicating medium employed, between some of the wireless telegraph systems in vogue thousands of years ago, especially those that employed the luminiferous ether as the communicating medium, and the wireless telegraph systems of to-day, in which case it would simply be another verification of the old proverb, "There is nothing new under the sun."

Polybius, the Greek historian, describes a telegraph system employed for military purposes, 300 B. C., in which torches were placed on high walls in prearranged positions to correspond to letters of the Greek alphabet, and by a suitable manipulation of the torches messages were thus transmitted to a distance. The Gauls, too, were wont to transmit important intelligence to a distance by a cruder but simpler method. A messenger was sent to the top of a hill, where he shouted his message, apparently to the winds. Soon from afar a voice answered him, and this voice repeated the message to another listener farther on, and thus, from one to another, the message sped, and it is recorded that in three days a message calling all the tribes of the Gauls to arms traveled in this way from Auvergne to the forests of Amorica in one direction and to the banks of the Rhine in another.

Later on came another wireless telegraph system—the semaphore telegraph—which was in operation all over Europe prior to and for some time after the introduction of the electric telegraph. This semaphore telegraph employed arms on posts akin to those seen to-day along every railway in the world, and a certain position of the arms,

[a] Reprinted by permission, after revision by the author, from Cassier's Magazine, January, 1902.

[b] Author of American Telegraphy and Maver's Wireless Telegraphy.

like the torches in the Polybius system, corresponded to certain letters of the alphabet, and by varying the position of the arms as required experts were able to transmit messages from one station to the other at the rate of two or three words per minute. The towers on the top of which the semaphores were erected were often 50 to 60 feet high, and were placed on eminences about 6 or 8 miles apart. In Russia alone there was a string of these towers from the Prussian frontier to St. Petersburg, a distance of 1,200 miles or more. Then, after the electric wire telegraph, came the electric wireless telegraph, and perhaps even a cursory review of this subject will show that it is not of as recent origin as it is popularly thought to be. For instance, it is known that over one hundred and fifty years ago electric signals were sent without wires across lakes and rivers. Dr. Watson, bishop of Landorff, then sent electric shocks across the Thames, and, subsequently, through the New River at Newington. Similar experiments were made by Franklin in 1748 across the Schuylkill at Philadelphia, and by Du Luc, a year later, across the lake of Geneva. In these instances, however, the water or earth was the conductor of the electric impulses.

It is fairly well known also that during the past fifteen or eighteen years there have been in limited use a number of wireless telegraph systems which have sometimes been termed induction telegraph systems, and in which electromagnetic impulses, or waves, are employed. Such systems are based upon the phenomena of mutual induction between wires, discovered by Faraday and Henry. Henry's experiments, made half a century ago, were chiefly with flat coils of wire, one opposite the other. When the circuit of one of such coils, containing a battery, was opened and closed, it was found that an electric current was set up in the other coil. This action also takes place between two straight, parallel wires, and when these parallel wires are sufficiently long, and the electromotive force in the transmitting wire is powerful enough, signals may be received in a telephone or other sensitive receiver, even when the wires are separated a distance of several miles.

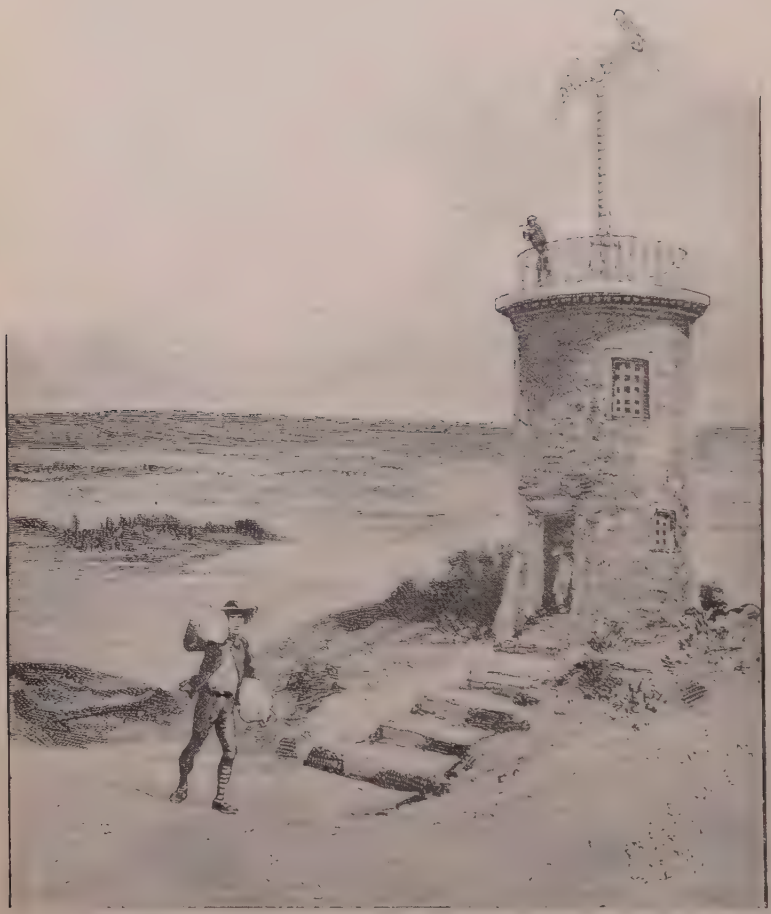
In 1892 Sir William H. Preece succeeded in transmitting Morse signals by this method to a distance of more than 3 miles, between Penarth, on the mainland, and the island of Flat Holm, in the British Channel, using a telephone as the receiver. More recently the same experimenter has met with success in establishing a wireless telephone circuit by means of which speech is transmitted between the Skerries light-ship and the mainland of Anglesey—a distance of nearly 3 miles—the parallel wire on the Skerries Islands being 750 yards in length and that on the mainland 3.5 miles in length, the ends of each wire terminating in the sea. On these systems both magnetic induction and electric conduction through the earth and water are utilized.



FIG. 1.—SIGNALING BY THE ANCIENT GAULS.

The messenger shouted or trumpeted.

FIG. 2.—A VISUAL TELEGRAPH APPARATUS, USED IN FRANCE IN 1792.



A FRENCH SEMAPHORE STATION IN 1795.

Remarkable as these results are, however, they have been almost totally overshadowed by those wireless telegraph systems in which electric waves, or ether waves, are utilized, and of which the Marconi wireless telegraph system is the best known. It is of this latter system, as representing, so far as the writer is aware, the most advanced development of this art, that the present article will briefly treat. It would obviously be far beyond the scope of a necessarily limited account to deal with all the wireless telegraph inventions that have been announced within the past few years.

When, in 1864, Clerk-Maxwell, who was, perhaps, the most noted mathematician of his day, made announcement of his celebrated electromagnetic theory of light, which theory involved the existence of electric waves in free space, many of the prominent physicists of the time set themselves the task of demonstrating by experiment the truth of this theory. It was not, however, until 1887 that the actual existence of electric waves in free space was demonstrated, the great honor of this accomplishment falling to Prof. H. Hertz, after whom such electric waves are now almost generally termed "Hertzian" waves. The old popular idea of electricity hardly conceived it as existing outside of a wire or other metallic conductor. The air was an insulator, and how, therefore, could electricity exist apart from a wire! Maxwell overturned this view, and told us that just as under the undulatory theory of light that which we call light is a result of ether vibration, so also is electricity a result of ether vibration, and that in so far as light and electricity differ it is only a question of the rate of vibration of the ether, those undulations of the ether which the eye recognizes as light occurring at a rate varying from 400,000,000,000,000 to 700,000,000,000,000 per second, while the frequency of the electric undulations of the ether vary from a few hundreds or thousands to 200,000,000,000,000 per second.

According to the undulatory theory of light, the undulations of the ether, of the frequency just mentioned, are set up by any source of light. Similarly, according to Maxwell's theory, undulations are set up in the ether by any source of electric oscillations—analogously, for example, as waves are set up in the atmosphere by a source of sound. Also, as those ether waves which correspond in frequency to light affect an organ of sight when they fall upon it, and as sound waves affect an organ of hearing when they fall upon it, so, it was reasoned, should the electric waves of the ether affect a suitable electric "eye," or receiver, when they fall upon it.

The manner in which Professor Hertz proceeded to show the existence of electric waves in free space was, briefly, as follows: It was already known that electric oscillations could be set up in a well-insulated wire or conductor; in fact, that the discharge of the Leyden jar is made up of a series of electric oscillations, as had been shown

by Lord Kelvin in 1853. Hertz set up electric oscillations by means of an electric oscillator, shown in fig. 1. This consists of an ordinary large induction coil, A, the terminals of the secondary coil being connected to brass balls, or knobs, and to which short metal rods, or wings, *w*, are attached. The knobs are separated by a small air space, across which sparks jump when the coil is in operation. At such times electric oscillations are set up, the rate of which varies with the electrical dimensions of the circuit.

Hertz assumed that if the electric oscillations thus produced set up corresponding waves in the ether of free space, these waves should, in turn, set up electric oscillations of corresponding frequency in a suitable receiver, or "eye," within the range of their influence. He therefore adopted as a detector of these waves a copper wire, D (fig. 1), of nearly circular shape, about 16 inches in diameter, but broken at one point. On the ends of this wire he placed small metal knobs, the distance between which could be easily regulated. This wire was held by an insulated handle, a few feet from the oscillator. With the room darkened, minute sparks were observed passing between the discharge knobs of the receiver; and the results of this simple experiment have been generally accepted as proof of the existence of electric waves in free space.

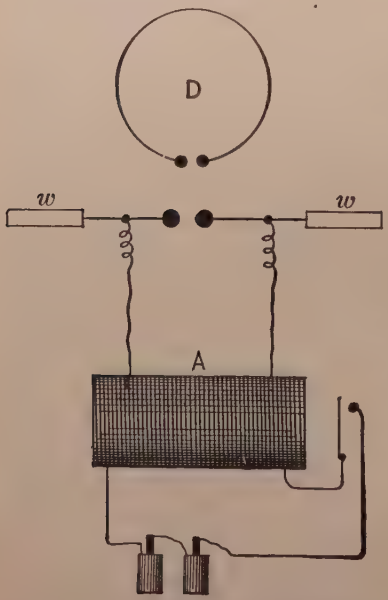


FIG. 1.—An oscillator and a Hertz detector.

Hertz, however, was not satisfied with this demonstration of the accuracy of Maxwell's theory, but also, in the course of his subsequent masterly experiments, showed that, like sound, heat, and light waves, the Hertzian waves could also be reflected, refracted, concentrated in parallel rays, and to a focus, etc.

By the Hertz receiver the distance at which electric waves could be detected was very limited, perhaps 10 or 12 feet at most, and hence it is not likely that much would have been done in the utilization of Hertzian waves for telegraphic purposes had progress rested there. Fortunately, it did not. Shortly after the experiments of Hertz, Dr. Branly discovered that loose metal filings, which in a normal state have a very high electrical resistance, lose this resistance in the presence of electric oscillations and become practically conductors of electricity. This he showed by placing metal filings in a glass

tube and making them part of an ordinary electric circuit (see fig. 2). When electric waves are set up in the neighborhood of this circuit, electromotive forces are generated in it, which appear to bring the filings more closely together—that is, to cohere—and thus their electrical resistance decreases, from which cause this piece of apparatus—the tube and its filings—is termed a "coherer." Hence, the receiving instrument, G, in the figure, which may be a galvanometer or a telegraph relay, that normally would not manifest any sign of current from the small battery, B, will be operated when electric oscillations are set up. Professor Branly further found that when the filings had once cohered they retained their low electrical resistance until shaken apart, for instance, by tapping on the tube.

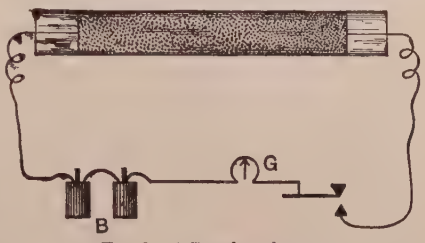


FIG. 2.—A Branly coherer.

In 1894 Dr. O. J. Lodge showed that the Branly coherer could be employed to transmit telegraphic signals, and in order that the filings might not remain "cohered" after the cessation of the electric oscillations, he devised a mechanical "tapper," on the principle of the common electric doorbell, the hammer of which was caused to tap the glass tube as long as the electric oscillations continued (fig. 3).

The filings thus virtually take the place of a key in the ordinary telegraph circuit. In the normal state the key is open; in the presence of electric oscillations the key is closed. Thus, by opening and closing the key for a longer or shorter period, signals corresponding to dots and dashes may be produced. In other words, by setting up electric oscillations for periods of time corresponding to dots and dashes, messages may be transmitted, and if at the receiving station a recording instrument (controlled by the coherer), such as is used, for instance, in the Wheatstone automatic telegraph system,[a] be provided, a record of the message in dots and dashes is obtained. And this, in short, is what is done in wireless telegraphy.

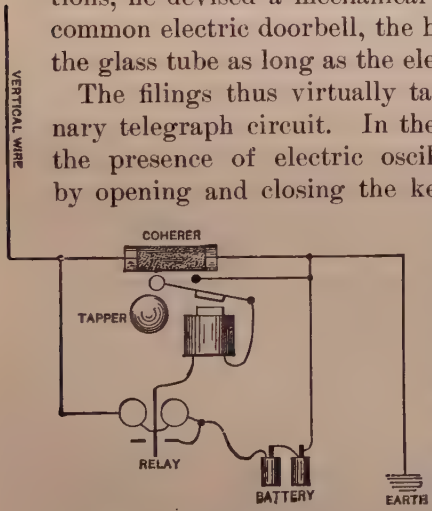


FIG. 3.—Lodge tapper and Poppoff vertical wire added.

In 1895–96 Poppoff and others utilized the coherer to show the existence of atmospheric electricity, using for the purpose a vertical wire connected to the coherer, as shown in fig. 3.

[a] Described in the present author's American Telegraphy.

While Dr. Lodge has since done important work in connection with wireless telegraphy, he was, at the time mentioned, presumably more absorbed in the subject from the purely scientific standpoint than otherwise, and although he then, in 1894, intimated that signals might be transmitted to a distance of half a mile by Hertzian waves, it was not until Marconi began his memorable work that really practical results were obtained.

In the operation of his wireless telegraph system Marconi uses an electric oscillator (figs. 4 and 5), the Branly coherer *k*, the Lodge tapper *t*, in a local circuit, and the Poppoff vertical wire A, at the sending and receiving stations, all of which devices, as has been shown, were well known, and it has been by modifying, improving, and perfecting these devices, and by adding others, that Marconi has been enabled to obtain his excellent practical results. The improvements and additions that have, perhaps, conduced more than anything else to the first successful results obtained by Marconi were those that related to the coherer and the vertical wire. The sensitiveness of the coherer he increased greatly by diminishing its size, compared with the Branly coherer, and by employing a mixture of nickel filings and silver—90 per cent of the former and 10 per cent of the latter metal. He also placed the few filings used in a vacuum. The other instruments, shown in fig. 5, are the relay, R, controlled by the coherer, and an ink-recording instrument, E, controlled by the relay. This figure illustrates the earlier arrangement of Marconi's devices. In it the coherer is directly connected with the lower end of the vertical wire by one of its terminals and with the earth by its other terminal. In his later work, Marconi has dispensed with the filings coherer, now employing a magnetic detector, which is much more sensitive than the coherer and does not require tapping.

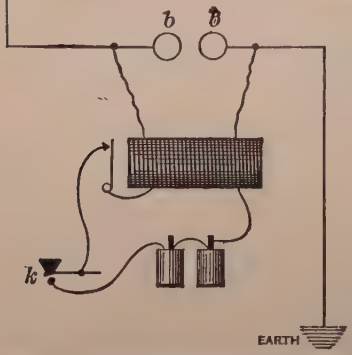


FIG. 4.—Details of Marconi's transmitting system.

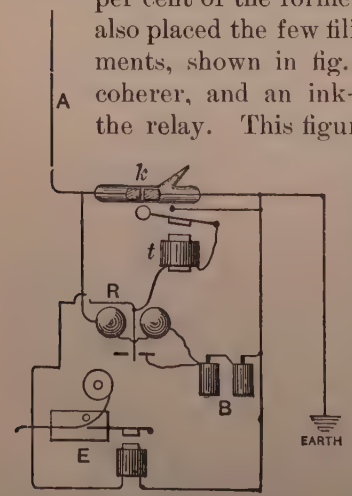


FIG. 5.—Outline of Marconi's earlier devices.

Beginning his experiments in Italy in 1895 with vertical wires 20 feet in height, Marconi found that he could get signals at a distance of 1 mile, and that by doubling the height of the vertical wire at both stations signals could be transmitted to four times that distance. Thus, with wires 40 feet high he could signal 4 miles, and with wires 80 feet high, 16 miles.

Since then Marconi has steadily increased the height and number of the vertical wires, and also the distance to which signals can be transmitted through free space, and in his latest tests about 50 vertical wires over 250 feet high are used, and the distance to which signals are transmitted is over 2,000 miles.

The amount of electrical energy employed in setting up the electric oscillations for a distance of, say, 200 miles is about 150 watts (10 volts and 15 ampères), or about one-fifth of a mechanical horsepower. The source of the electrical energy is a storage battery, which latter is usually charged by a large number of dry cells. In passing, it may be remarked that an ordinary telegraph relay may be operated at a distance of 200 miles at an expenditure of 3 watts at the transmitting end of a telegraph wire, or with one-fiftieth of the energy used in operating the electric oscillator in question. The actual energy required to operate the telegraph relay is about 0.24 of a watt, the rest of the energy being consumed in the wire itself. It must not, however, be assumed from this that the coherer is a less sensitive electric receiver than the relay; nor will it be, when it is reflected that the electrical energy expended in the case of the relay is, so to speak, mainly confined to the wire, as, analagously, sound waves are confined within a speaking tube, whereas the electrical energy of the oscillator is radiated into space in every direction, and thus but a small portion of the total energy reaches the receiving vertical wire. It has been calculated that the electrical energy received on a surface 1 foot square at a distance of but 1 mile from the oscillator is less than one three-hundred-millionth of the total energy radiated, and it may be noted the energy actually radiated as electric waves is a mere fraction of the energy consumed in and at the oscillator.

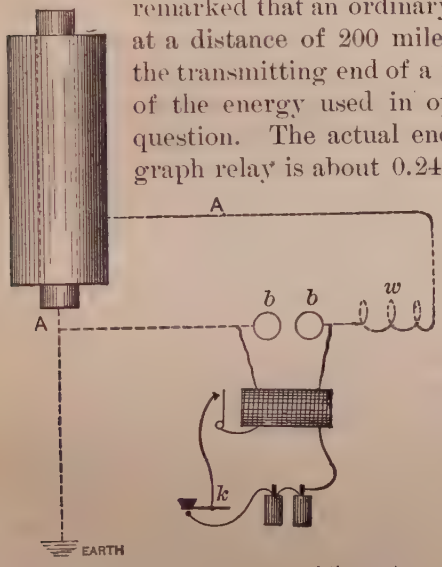


FIG. 6.—Marconi's cylinder transmitting system.

From the results obtained by Marconi and others it appears that the effect of increasing the length of the vertical wires is to give a greater radiating surface at the transmitting end and to present at the receiving end a larger surface upon which a greater number of circles of waves may fall, each circle of waves adding to the electrical energy set up in the receiving vertical wire. This view is seemingly borne out by experiments made by Marconi with a metal cylinder 4.1 feet high and 1.3 feet in diameter, with which arrangement signals have been transmitted over 31 miles (fig. 6). The chief object of this

arrangement, however, is to secure a radiator having large capacity for syntonic purposes, to be referred to presently.

The vertical wire is usually of stranded copper, about one-fourth inch in diameter, although Marconi for this purpose uses also strips of wire netting about 2 feet broad. On land the wire or netting is supported by masts of proper height, securely guyed. On ships the ordinary masts suffice. It is not necessary that the wire be suspended strictly vertically so long as the desired vertical height is obtained. The wire is thoroughly insulated from the mast at the top by sticks of rubber or ebonite, and is led in through an open window or hatchway to the room where the transmitting and receiving apparatus are situated. This thorough insulation is necessary, because, although the discharge knobs of the oscillator are separated by an air space of only half an inch or less, the induction coil used in connection with the oscillator is often capable of producing a spark that will jump 10 or 12 inches through air. The actual appearance of the induction coil, discharge knobs, vertical wire, etc., is well illustrated by the upper figure on Plate III. The heavy current and high pressures in the circuits of the oscillator have necessitated the employment of a much larger key for manipulating the oscillator circuits than is used in ordinary Morse telegraphy.

At an early period of the practical history of Hertzian-wave telegraphy it was seen that the usefulness of this art might be considerably curtailed by the fact that but one message could be transmitted between any two stations within the sphere or "radius" of influence of a transmitter, since the attempt to transmit even two messages at one time would result in an unintelligible mixture of both messages. Several inventors have been at work trying to overcome this defect, and, it is claimed, with success, notably Dr. Lodge, Sig. Marconi, and Dr. Slaby. The plan followed by these gentlemen has been that of employing a syntonic or tuning method; that is, the transmitting and receiving circuits are adjusted or "attuned" to a given rate of electrical oscillations.

It is a well-known experiment that when two tuning forks having an identical fundamental rate of vibrations are placed in suitable proximity either fork may be set into vibration by air waves set up by the other fork and neither will be set into vibration by another fork of a different note. The tuning fork is a persistent vibrator by virtue of two qualities which it possesses—elasticity and inertia. When struck a smart blow, it moves from its point of rest; directly its elasticity returns it to its point of rest, its inertia carries it past that point, its elasticity returns it to zero point, inertia carries it past, and so on, until the resistance of the air and other causes stop it. Analogously, an electrical circuit may be given, in almost any desired



FIG. 1.—A HERTZIAN WAVE WIRELESS TELEGRAPH STATION.



FIG. 2.—THE NANTUCKET LIGHTSHIP, EQUIPPED WITH MARCONI APPARATUS BY MEANS OF WHICH ALL PASSING WHITE STAR, CUNARD, AND OTHER ATLANTIC STEAMERS ARE SIGNALED TO THE NANTUCKET ISLAND STATION, SHOWN ON PLATE IV.



FIG. 1.—THE STATION APPARATUS.



FIG. 2.—THE WIRELESS TELEGRAPH STATION OF THE NEW YORK HERALD AT SIASCONSET, NANTUCKET ISLAND, MASSACHUSETTS.

proportion, the equivalents of mechanical inertia, elasticity, and resistance, in inductance, capacity, and ohmic resistance, respectively; and the rate of electric oscillation of a circuit may be varied by varying these factors—the smaller the factors the higher the rate of oscillation.

When, then, the receiving circuit of a wireless telegraph system is accurately tuned to oscillate in harmony with the transmitting circuit, which can be done by giving the respective circuits practically equal inductance, capacity, and resistance, the receiving circuit will respond only to the oscillations set up by a transmitter correspondingly tuned. At least, this is, briefly, the theory on which these experiments are based. In experimenting, Marconi and others have, it is stated, found that perfect syntony between the respective stations is not absolutely essential, but that if there is a marked divergence of frequency of oscillation between them the receivers will not respond to any but their correspondingly attuned transmitters.

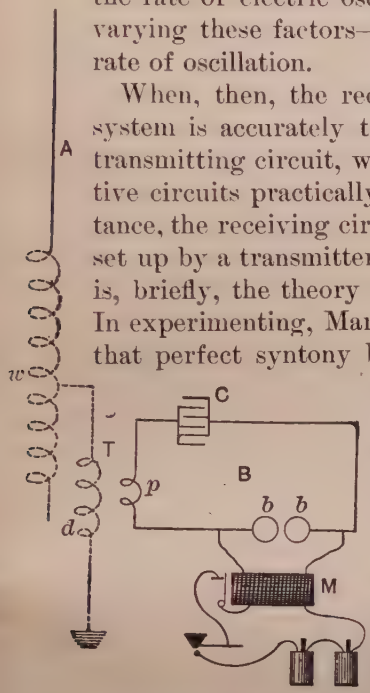


FIG. 7.—Marconi's tuned transmitting circuit.

The arrangement of Marconi's tuned transmitting and receiving circuits is outlined in figs. 7 and 8. It will there be seen that the oscillator and the coherer *k* are not connected to the earth, as in Marconi's first experiments, but are kept in electrical connection therewith by a small induction coil *T*. In fig. 7, *A* is the vertical wire, which is attached at its lower end to a coil of wire *w*. The end of the wire *d*, which forms part of the secondary wire of the induction coil *T*, may be connected to any desired turn of the coil *w*. By this means the inductance of the vertical wire circuit may be varied, and its oscillation period thereby be made to correspond with that of the circuit *B*, of the oscillator, which includes the primary wire of *T*; *C* is an adjustable condenser of very small capacity, by varying which the oscillation period of the circuit may readily be varied. An electrical condenser is virtually a Leyden jar, arranged in a convenient form. In this case it consists of a few sheets of tin foil or copper, the alternate sheets being separated from each other by thin sheets of paraffin paper. A key controls the storage battery circuit, as shown in fig. 7, and, thereby, the oscillator circuit; *M* is the induction coil of the oscillator.

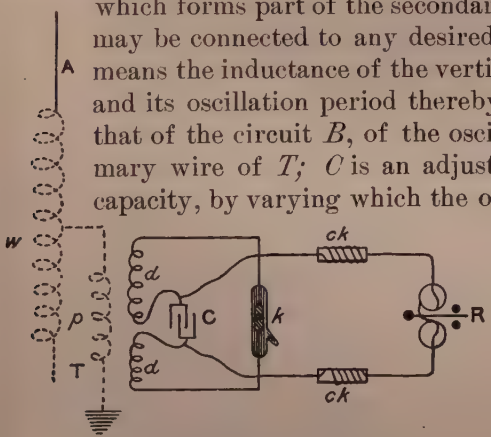


FIG. 8.—The tuned receiving circuit.

The tuned receiving apparatus is shown in fig. 8. In this figure, A is again the vertical wire with the turns of wire w, to which is attached the primary wire p of the induction coil T; d is the secondary of the same induction coil; ck are "choke" coils; k is the coherer, c is a condenser, and R is the relay. The induction coil T acts virtually as a step-up transformer, materially enhancing the electromotive forces of the received oscillations, and thus increasing the signaling distance.

Marconi has found it important that the oscillation period of the coherer circuit, shown in the figure in solid lines, shall be the same as, or an octave of, the oscillation period of the vertical wire circuit, shown by the dotted lines. This can be done by making the secondary coil p, of the coil T, equal the length of the vertical wire A. The transmitter circuit is then adjusted so that its oscillation period corresponds with that of the receiving circuit. This is brought about by varying the capacity of the condenser in fig. 7. The method of obtaining this "balance," as practiced by Marconi, is to begin with very little capacity in the condenser, and adding to it until the best results are obtained at the receiving station. If, when the best results are obtained, still further capacity is given to the condenser in the transmitting circuit, the signals fade away, showing that then the two circuits are out of harmony.

Marconi also found that by means of tuned apparatus a much greater distance may be reached, with a given source of electrical energy and height of wires. For example, a transmitter which would affect a tuned receiver 30 miles away would not affect a nontuned receiver 160 feet distant. This, it may be assumed, is because in the case of the tuned receiver the faintest oscillations, or electromotive forces, set up in the receiving circuit by the incoming waves are in unison with those waves, and successive incoming waves amplify the oscillations in the receiver circuit until they affect the coherer; whereas the oscillations which the same waves tend to set up in the nontuned receiver circuit are, so to speak, out of step with the natural rate of oscillation of the nontuned circuit, and thus as frequently oppose as assist the natural oscillations of the circuit.

In connection with the experiments carried on by Marconi, it is reported that two different messages have been received at one time on a vertical wire, two sets of receiving apparatus, each attuned to a different rate of oscillation, being connected with the same wire. To those who have had experience with Gray's harmonic system of wire telegraphy,[a] in which three and four instruments, attuned to transmit and to receive different rates of electrical current pulsations, have been successfully and separately operated on one wire, this will not appear astonishing, since it is quite conceivable, if it be granted that wireless transmitting and receiving apparatus can be successfully attuned, that two or more receiving instruments might be connected

[a] Described in Maver's American Telegraphy, fifth edition.

with one vertical wire, and each set of apparatus select and respond only to the particular rate of oscillations to which it is attuned.

However, while the successful operation of contiguous tuned circuits is quite within the possibilities, it is reported, as a result of numerous tests in France and elsewhere, that freedom from interference with tuned apparatus is not yet secured. But if by the use of tuned apparatus nothing else were gained than the ability, with a given amount of electrical energy and a given height of vertical wire, to transmit signals to a greater distance than is possible with untuned apparatus, it must be considered a decided advance in the art, and, judging by the whole progress of electrical telegraphy, it is safe to say, when so much has already been achieved, that the necessary improvements to obtain at least practical freedom from interference between adjacent apparatus will ultimately follow.

The specimen of a dot and dash wireless telegraph record given in Fig. 9 is a facsimile of bulletins "caught on the wing" during the yacht races of 1899 in New York Harbor. Mr. Marconi had his apparatus on the steamship *Ponce*, and was sending bulletins of the progress of the race to the Mackey-Bennett cable ship, some miles away, when this specimen and many others were recorded by a set of



FIG. 9.—Specimen of a dot and dash wireless telegraph record.

Clarke wireless telegraph apparatus which the writer was supervising on the steamship *Le Grande Duchesse*. This was probably the first instance of tapping Hertzian wave signals, in the United States at least. It will be understood that Shr. is an abbreviation for *Shamrock*. Other abbreviations were used in these bulletins, as Col. for *Columbia;* abt. for about; bd. for board, etc. The present speed of signaling by wireless telegraphy when the filings coherer is used, is from 10 to 20 words per minute; but it seems reasonable to expect that, with further improvements in the art, expert manipulators of the key should eventually attain a considerably higher speed of transmission.

For practical purposes there is not much doubt that wireless telegraphy will find its greatest field of usefulness between vessels at sea, or between vessels and the mainland, or between points divided by the sea where it is not deemed feasible or profitable to lay a cable. Numerous examples of such uses are already in evidence. There is, for example, a wireless circuit between some of the Sandwich Islands; another between the Lizard, Cornwall, and St. Catherines, Isle of Wight, 186 miles apart, and between Poole and St. Catherines, 31 miles apart. The British Admiralty have also adopted the system for many of their war ships and for some of their land stations. In all,

they have about 40 sets of such wireless telegraph apparatus installed. The length of vertical wire of these stations is about 150 feet. The war ships thus equipped have signaled each other when 100 miles apart. The wireless system is also installed at different points on the continents of Europe and America—at La Panne, Belgium, for example, and at Dorkum Island in the North Sea off the mouth of the Ems.

A number of light-ships have also been equipped with the wireless telegraph systems; for instance, the Goodwin Sands light-ship, the Borkum light-ship, 25 miles from the island of that name, and the Nantucket light-ship, off the Massachusetts coast, from which station passing vessels are daily reported to the mainland.

Many mercantile steamships have also been equipped with the same system, notably the *Kaiser Wilhelm der Grosse*, of the North German Lloyd Steamship Company, the *Deutschland*, of the Hamburg-American Line, and the vessels of the Cunard Line, and many others. Frequently vessels thus equipped have communicated with one another by wireless telegraphy in mid ocean, and while out of sight of each other, communication being thus kept up for hours while the vessels were passing in opposite directions.

There is little doubt that the use of wireless telegraph systems by the navies of the world will become general in the near future. There are several reasons why such systems are especially applicable to, and desirable on, war vessels, which depend so largely on signaling. For instance, signaling by the Hertzian waves is more successful over water than over land, greater distances being reached over water. The vessels already carry the necessary masts for the vertical wires; the apparatus, including batteries, does not require to be portable; there is at present no other practicable method of signaling at sea to a distance of even a few miles in foggy or hazy weather.

With regard to the use of wireless telegraphy for military purposes in actual warfare, the problem is somewhat different and the obstacles to its use are considerable. Thus the question of obtaining and transporting the masts for the vertical wires is a serious one. This was one of the difficulties met with in the South African war. The matter of providing in an easily portable and reliable form the electrical energy required for the operation of the oscillator is also likely to be rather difficult under some circumstances. Should the cylinder arrangement employed by Marconi be found suitable for land work, this would be a decided gain, and if by this means a reasonable distance, say 15 to 50 miles, could be covered by wireless telegraphy, it would be a very valuable addition to military signaling in the field.

There is, however, nearly always in land operations the alternative of wire telegraphy, and while the difficulties of transporting the poles and wires for such systems are frequently very great, they have rarely been found insurmountable, and where this may be the case, as when

an enemy is between a relieving army and a beleaguered garrison, it is very probable that the enemy, by keeping up a "cross fire" of electric waves, could prevent communication by means of wireless telegraphy with the beleaguered army.

As to the commercial or monetary value of wireless telegraphy, it is yet too early to comment. Commercial trans-Atlantic wireless telegraphy has been promised since the early part of 1901, but it is not yet, at the end of 1902, accomplished. It is understood that the Marconi Company receives from the British Admiralty £100 per annum for fifteen years, presumably during the life of patents, for each station equipped. The Borkum lightship is what may be termed a wireless telegraph "pay station," and according to the German postal authorities, which control this station, 565 messages were handled during five and a half months, or about three messages per day, of which 518 messages came from ships at sea, while 47 were transmitted to ships. A large percentage of these messages were to and from North German Lloyd steamers.

Since the first announcement of Marconi's successes with wireless telegraphy many aspirants for honors in the same field have naturally arisen, but so far as actual commercial results are concerned Marconi has hitherto kept well ahead of other workers along this line. But more recently such companies as the De Forest in this country and the Slabo-Arco and the Braun in Europe are operating in numerous instances with success.

To obtain the greatest degree of usefulness from wireless telegraphy, when it is employed to prevent collisions at sea and to send information from vessels in distress or when approaching or departing from their respective harbors, which are popularly supposed to be the functions for which this system is especially adapted, it would appear to be essential that every vessel sailing the main should be equipped with the apparatus. The writer can say from experience that it requires a considerable degree of expertness to maintain the apparatus in proper working order, and even when code signals only are employed a fair amount of intelligence is required. It is therefore a question whether the requisite skill and intelligence would be available at all times on all kinds of craft.

There are, however, doubtless a great many places where the necessary expertness of operators is available, and in which, therefore, the full value of the system will be realized. In fact, it may be stated that a vastly larger employment of wireless telegraphy is already assured, since the Lloyds, whose extensive maritime interests are world-wide, have entered into a contract with the Marconi International Marine Communication Company to equip all their coastwise signaling stations with this system, and to transmit and receive messages to and from all passing vessels similarly equipped, at a regular

tariff rate of about 12 cents per word, this agreement to extend over a period of fourteen years, and in this country as well as in Europe. Already in the comparatively few instances where the system has been introduced its great utility and importance have been amply demonstrated.

A number of vessels equipped with wireless telegraph apparatus have signaled for aid for themselves and for other vessels in distress; necessary supplies for light-houses have by this means been procured in emergencies, and in other ways life and property have already been safeguarded by the aid of this latest wonderful utilization of nature's greatest mystery, the ether, by the genius of man.



TRUCK ELEVATED. LOAD, 6,000 POUNDS.

Minimum headroom double sheave electric hoist, suitable for all kinds of freight. Any reasonable load elevated and transported.

TELPHERAGE.[a]

By Charles M. Clark.[b]

Definition.—Telpherage is derived from two Greek words "τελε" and "φερω." "Tele" means far, and "ferro" means to bear or to carry. Therefore, telpherage means far-carrying. The same word "tele" appears in telegraph and telephone. The word was originally invented by the late Prof. Fleeming Jenkin, who was the early spirit of telpherage, and but for his untimely death telpherage would be even more extensively used. Like many other words, its meaning has varied. In the beginning it meant, practically, aerial electrical transportation, but now it has been brought back to its original meaning, which is the transportation of material to a distance by electricity, overhead, or sometimes on the surface, or even underground. In the latter case, it is termed "tubular dispatch." Therefore, telpherage may be concisely defined as the electrical transportation of material. The method of applying it is an engineering problem and must depend upon local conditions, and even to-day the term "telpherage engineering" is becoming a common expression. It will be noticed that the word "automatic" is left out in these definitions. The reason for this is that it is a commercial question, and in cases where a man is required to attend to certain portions of the work, it is often cheaper for the man to go with the load than to use automatic devices. As to whether it is better to make an installation automatic or otherwise, depends entirely upon the comparative cost of the two methods of operation. In this connection it may be said that with telpherage plants the word "telpherman" is now often used.

History.—The early history of telpherage closely resembles that of the electric railway. Before the successful pioneers in electric street-railway traction had finally accomplished satisfactory results,

[a] Reprinted by permission, after revision by the author, from Transactions of the American Institute of Electrical Engineers, New York, Vol. XIX, April, 1902, pp. 391–409.

[b] A paper read at the one hundred and sixty-fourth meeting of the American Institute of Electrical Engineers, New York and Chicago, April 25, 1902.

many men had experimented, and it is well known that some forty years ago an electric railway was operated having a speed of several miles per hour. It seems that it is necessary, with all successful applications of power to the transportation problem, that much preliminary work, seemingly unproductive, must be done. It often happens, as in the case of early telpherage, that the times were not ripe for its commercial adaptation. In the history of telpherage in England, a telpherage line was installed using what was then called the series system, whereby it was necessary to use a telpher with a number of trailers. One section was positive and the next negative, the current passing from one section of the track to the other through the motor, thereby completing the circuit. In passing over the insulator between the positive and the negative sections, there necessarily occurred considerable sparking, which greatly increased the cost of maintenance. It was also necessary to always have trains of certain lengths. There were many other disadvantages, such as having to use a track made of round bar rail and the difficulty of manufacturing reliable electric motors. If it was desired to install a telpherage plant it was always necessary to put in an engine, boiler, and dynamo. In comparison with its early history telpherage to-day possesses the advantage that every factory, where there is need for telpherage, either has its own electrical plant or the power may be rented from existing central stations or even street-railway stations. There are also to-day for aerial transportation most excellent cables made especially for telpherage work, and likewise, where it is more desirable to use than solid rail cable, special shapes have been devised which give most excellent results. Motors, controllers, and carriers of great reliablity are now manufactured following the methods developed by the best railroad practice.

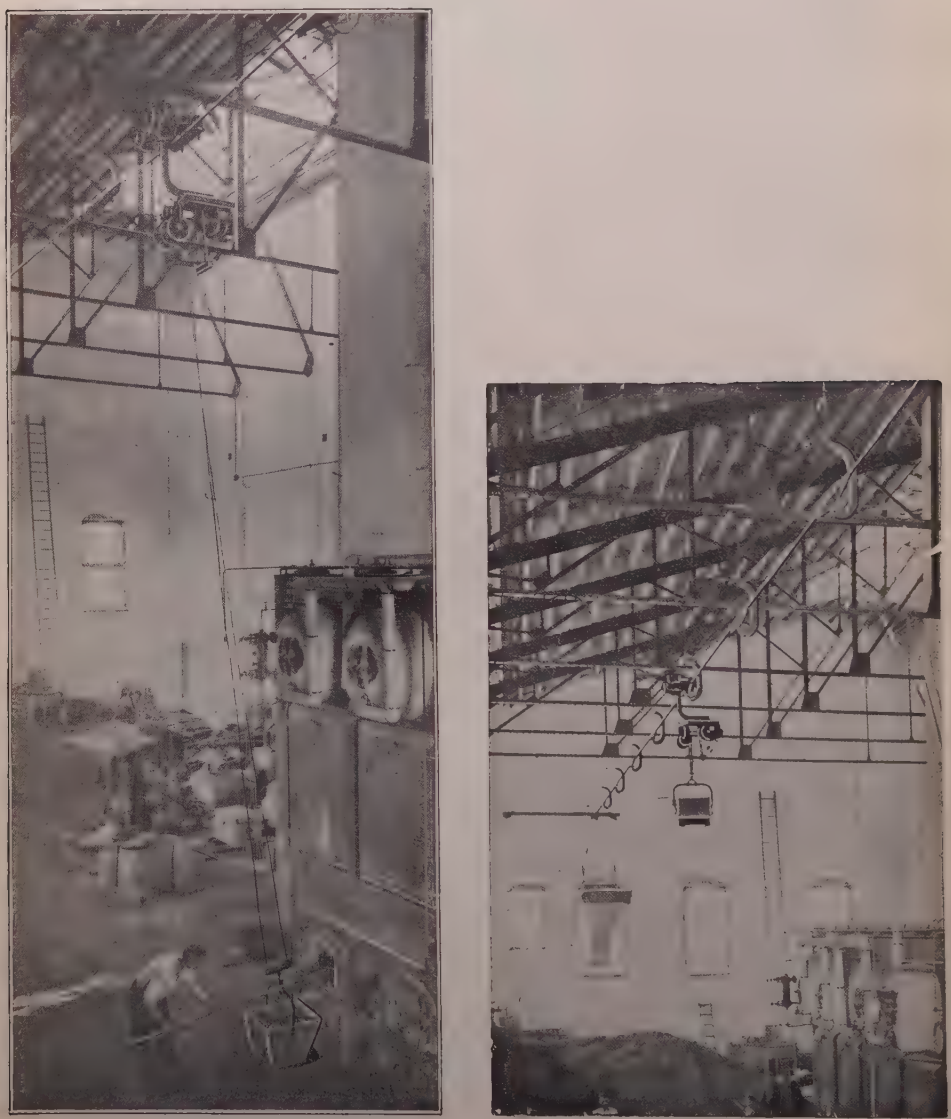
Before it was decided to enter into the present commercial adaptation of telpherage, an engineer visited all the electrical manufacturing plants and electrical installations in Europe, and found that nothing was being done in the transportation of material electrically. In the United States many experiments had been made, but the inventors were always seeking the unobtainable. Upon careful research, it was found that there were 450 patents directly applying to telpherage and several hundred more which pertained indirectly to this subject. Most of these original inventors were, however, too ambitious, and there was hardly any limit to the number of miles per minute which was to be achieved by the new and wonderful agent, electricity. Not only material was to be transported, but also passengers, and beautiful cars of mahogany were built and put in experimental operation. Cigar-shaped carriers were devised, some of which made a speed of 2 miles per minute or more, and when it was impossible to attain a greater speed there was great discouragement. There are no authentic



FIG. 1.—TRACK WITH "S" CURVE.



FIG. 2.—CABLE CONSTRUCTION, LINE 97 FEET FROM GROUND, ILLUSTRATING SUSPENSION CABLE, TRACK CABLE, AND HANGERS.



CABLE CONSTRUCTION WITH TELPHER, ELECTRIC HOIST, AND BUCKET.

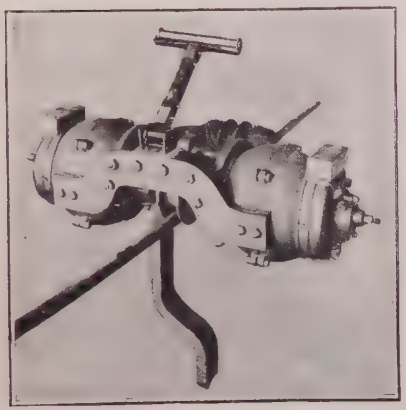


FIG. 1.—CENTER-BEARING TELPHER.

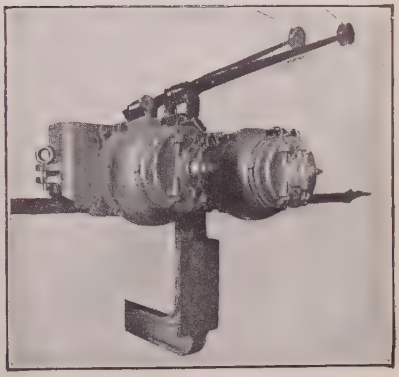


FIG. 2.—SIDE-BEARING DOUBLE TROLLEY.

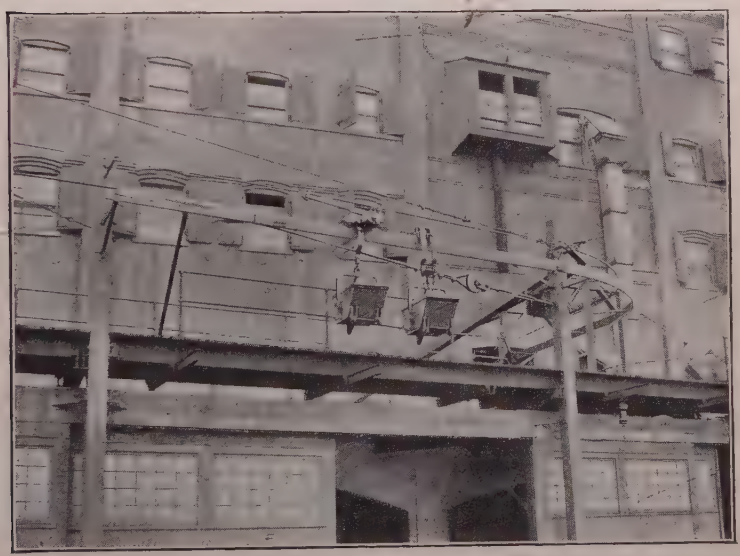


FIG. 3.—SOLID RAIL COMBINED WITH CABLE CONSTRUCTION

Capacity, 150,000 pounds of ashes in ten hours. Average power consumed about one horse power.

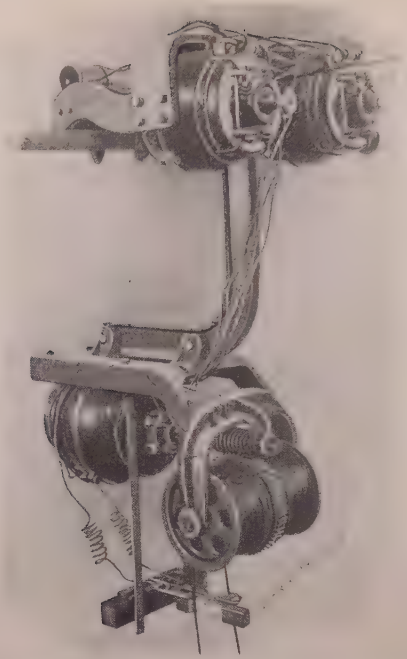


FIG. 1.—ELECTRIC HOIST SUSPENDED FROM TELPHER.

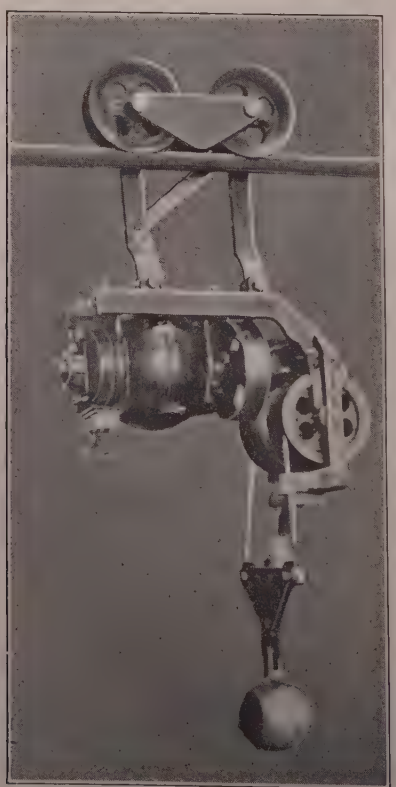


FIG. 2.—ELECTRIC HOIST AND TRAILER.

examples of much more than experimental work, namely, merely conveying material between two points, generally in a straight line, placed in some vacant lot or loft, and there seemed to be a desire to force the method of transportation according to certain preconceived ideas, rather than to pay the necessary attention to its commercial adaptation.

Construction.—On account of various advantages in regard to the distribution of material—such as depositing at an elevation—most of the telpherage plants thus far installed have been overhead. As engineers, you will be most interested in hearing what has been accomplished. The descriptions are, therefore, confined to overhead work. Under the head of construction, it may be stated that the track is made

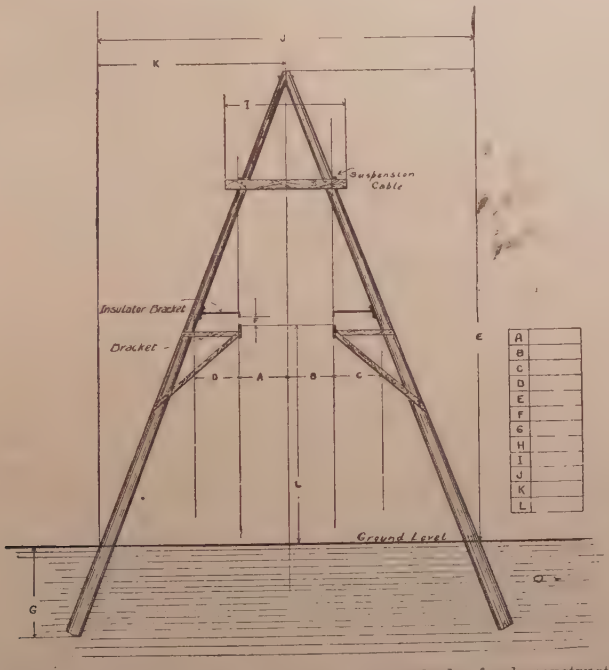


FIG. 1.—Supporting pole, double line. One of the simplest methods of pole construction for double lines. Especially recommended for long lines and where trees are available.

of cable, especially drawn, either of standard wire or lock coil type, which latter has a strength approximating 95 per cent that of the solid bar, or else solid rail, either of flat, girder, or bulb type.

The cable tracks are supported every 100 feet, provided it is convenient to erect poles or structures. Where there are deep ravines or between upper stories of factories, the span is made to correspond with the distance, and can be made of any reasonable length. In addition to the track cable, upon which the telpher runs, there is also what is known as the suspension cable. As is well known, it would be impossible to prevent considerable sag in the track cable and therefore the track cable is suspended from this suspension cable by means

of hangers. The number of these hangers would depend upon the length of the spans. It will be easily seen that it is possible to have the center of the spans higher than the ends by merely raising the suspension cable and the hanger. This obviates one of the early difficulties met in the use of cable for telpherage, as there is now no objectionable deflection in the cable when the telpher approaches a bracket. There are several methods of connecting the track and suspension cables by means of the hangers. The sizes of the cable, hangers, and brackets vary, depending upon the weight which comes upon each individual span. The support was either simple poles with a bracket, or what is known as the "A" construction or ordinary cross bents. Cable construction costs less than solid rail, except where

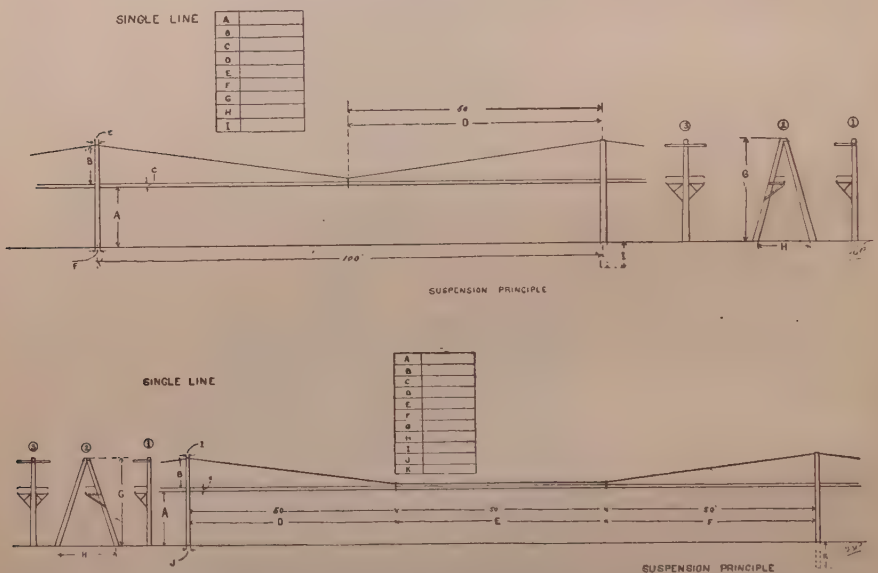


FIG. 2.—Other forms of pole construction, showing single and double lines. The track cables are supported by another cable, which is called the suspension cable. It would be impossible with long spans to stretch a cable so that under load there would not be considerable deflection. This deflection or sag is taken up by the suspension cable. Not only can we make the track cable horizontal but even higher in the center than at the terminals.

there are many switches, in which cases the prices of solid rail and cable approach each other. In general, cable lines are recommended for straight lines, except where the weight is excessive.

In solid rail construction, the supports are ordinarily placed 16 to 20 feet apart; longer spans are used if it is not convenient to erect supports. On long spans, the track consists of a girder rail with the track rail above it. It is not possible to give any general rule as to what kind of track it is advisable to use, as this is a factor of the length of the spans and the weight. The weights conveyed thus far by telpherage vary from 125 to 10,000 pounds, and the cost varies accordingly. It will be readily understood that when the weights are

greater, the supports must be nearer together, and the cables or girders heavier. Running parallel to the track rail, either above or at the side, and depending upon the amount of head room, are stretched one or more trolley wires; one wire, if the track be used as a return. If, however, it is desired not to use the track as a return, or to use alternating current, two trolley wires are employed. There are many other details of construction which the illustrations show better than any description.

Telphers.—According to the construction, telphers are divided into three distinct classes, center-bearing, side-bearing, and alternate-bearing. The center-bearing has two motors, one on each side of the track; the side-bearing has both motors on the same side, and the alternate has one motor upon one side of the track and the other motor upon the other side, but not upon the same shaft. Illustrations of some of these telphers are shown, also the same in operation. All the weight in the side-bearing telpher is utilized for traction, and the load is suspended beneath the driving wheels. Sometimes two telphers

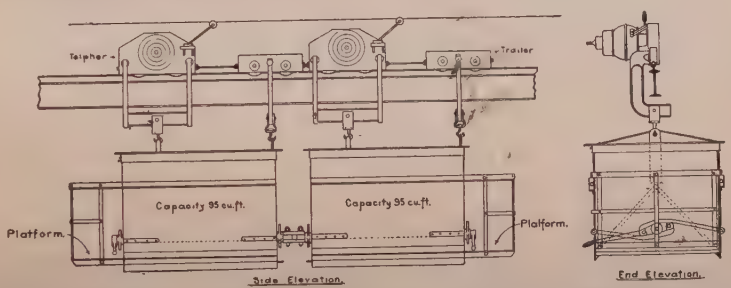


FIG. 3.—The double telpher; maximum traction; capacity, 4 tons of coal, or 95 cubic feet; speed, 800 to 1,200 feet per minute. Side-dumping bucket operated by telpherman; controlled from either end. Telphers can be operated separately. Three of these double telphers have a capacity of 250 tons of coal per hour over 2,000 feet of track. Labor, power, and maintenance less than 1 cent per ton.

are connected up together in a single truck, this giving what is called a double telpher; or a trailing wheel is used after a double telpher in order to distribute the weight over a greater portion of the track. This is necessary when the weight of the load to be carried is great. Fig. 3 shows quite fully this weight distribution. In all telpherage work gears are rarely used except for very heavy work or on steep grades. The frames of the later telphers are made in one casting, and the driving wheels are of steel, this having been determined to be the best material.

Motors.—The motors are waterproof and dust proof and are compound wound for automatic work. When a telpherman goes with the telpher the series winding is employed. There is also used a special series coil to give greater torque when starting. The telpher is placed above the track, thereby keeping the motors from injury, while there is also no danger of their coming in contact with the carriers or being otherwise injured.

Hoists.—The hoist is suspended below the telpher, or sometimes from a trailer drawn by the telpher. Special attention has been paid in the later designs of hoists to use as little head room as possible. It was deemed best at first to combine the telpher and hoist all in one, but there were so many cases where it was necessary to use the telpher alone without the hoist, and also where it was advisable to put the hoist on the trailer instead of on the telpher, that experience has shown it is better to make the telpher and hoist two separate pieces of apparatus. Greater simplicity has also been obtained and a correspondingly lower maintenance reached. There are many other interesting details concerning hoists, as to the speed, lift, and construction, which it is necessary to omit here.

Brakes.—Two distinct types of brake are used on telphers, either hand brakes or solenoid brakes, both of which are arranged to apply

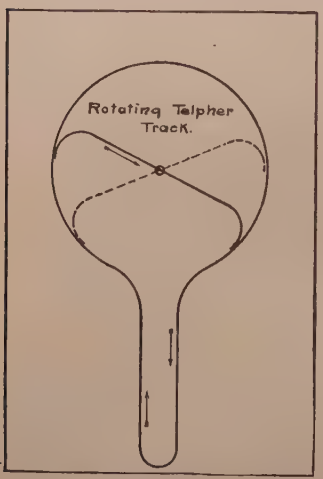


FIG. 4.—Plan of circular coal-storage shed with rotating telpher track.



FIG. 5.—Space-covering or movable telpher track.

pressure to the wheels or to grip the track. In regard to the solenoid brake, it is only necessary to explain that it works automatically, the solenoid being placed in series with the armature. A spring normally holds the brake on the wheel or the track. If, however, from any cause the amount of current passing through the solenoid is reduced, whether by means of external resistance or by reason of the additional counter-electromotive force generated by the armature, due to running at a high speed, the solenoid becomes weakened and the brake is applied. An air cushion is arranged so that the brakes will be applied gradually.

Trailers.—It is often advisable where a large amount of material is to be carried, especially over one track, to use trailers. These consist generally of a two-wheeled truck, below which is suspended a bucket or other suitable form of carrier, or even the hoist, as the case may require. For heavy traffic it is customary to arrange a long train

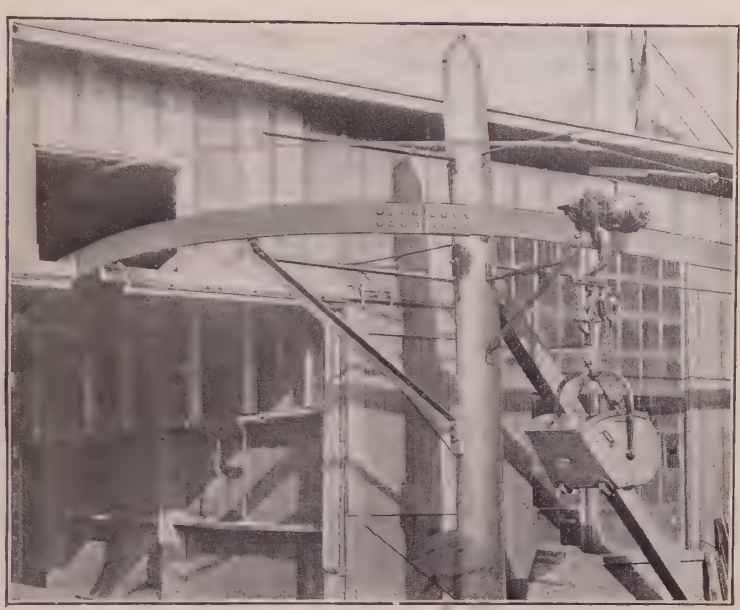


FIG. 1.—TELPHER WITH AUTOMATIC DUMPING BUCKET TRAVERSING A CURVE.

Automatic in operation.

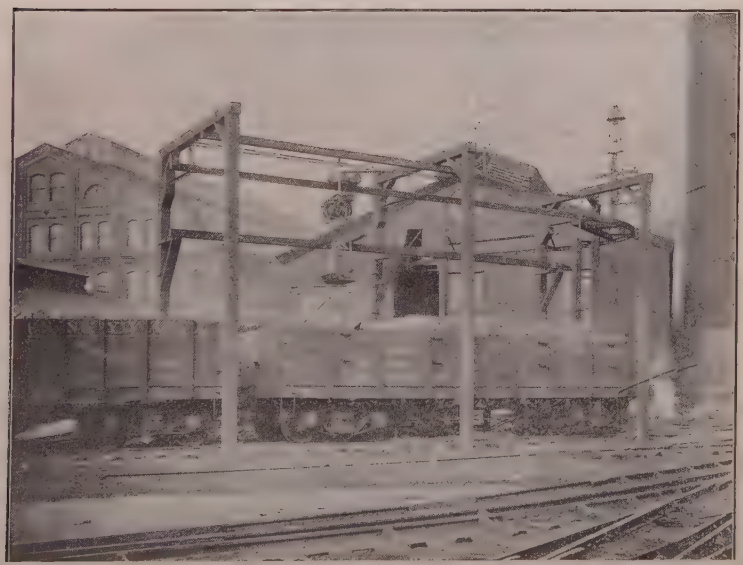


FIG. 2.—STANDARD HOIST, WITH TELPHER AND AUTOMATIC DUMPING BUCKET, FILLING CARS.

Automatic in operation. Compound curve.



FIG. 1.—LOAD OF MISCELLANEOUS FREIGHT APPROACHING WAREHOUSE (TERLPHERMAN'S SEAT ATTACHED TO TELPHER FRAME EXTENSION).

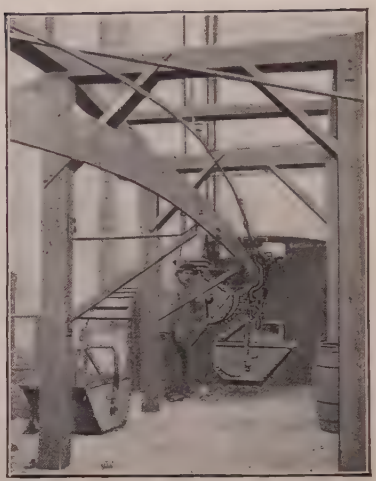


FIG. 2.—BUCKETS FILLED FROM CHUTES.

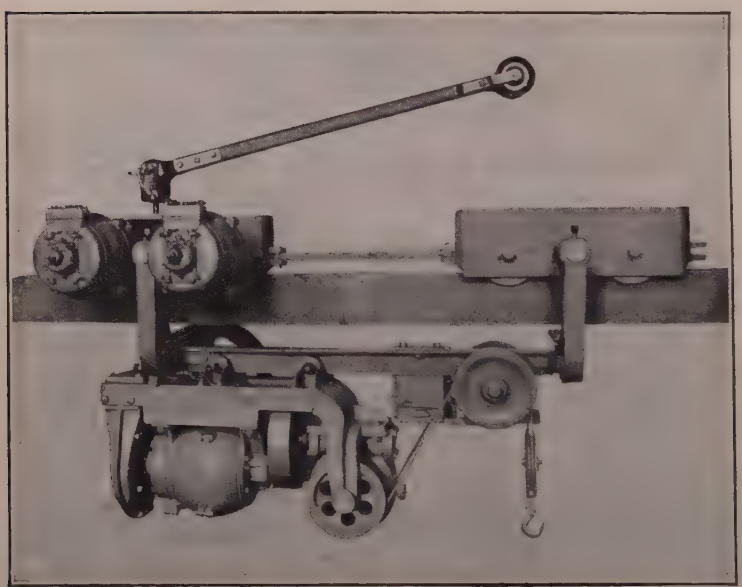


FIG. 3.—TELPHER, TRAILER, AND MINIMUM HEADROOM HOIST.

The hoist moves to the load.

carrying as much as 10 tons. The order of procession is, first, a telpher with four or five trailers, then another telpher and four or five trailers, and a telpher at each end. The placing of these telphers at intervals greatly adds to the traction, while the distribution of weight over the whole span, or over two or three spans, enables much lighter construction to be used for greater capacity.

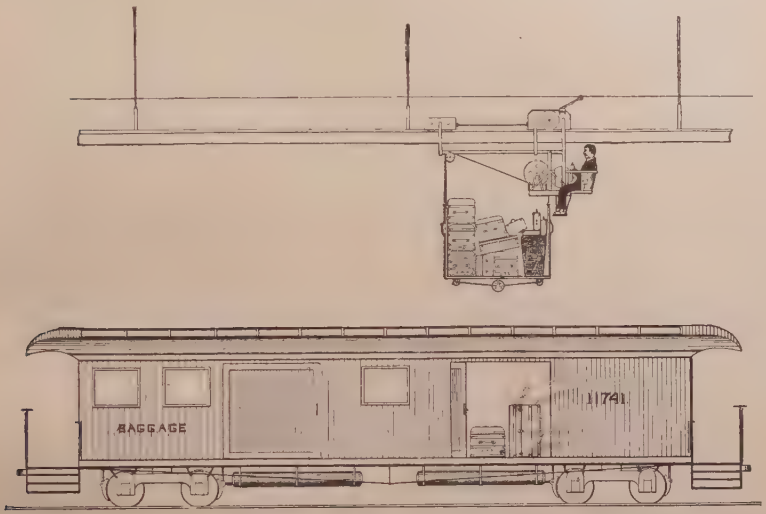


FIG. 6.—Overhead telpher tracks, parallel to but at the side of railroad tracks. Standard railway baggage truck. Telpher, trailer, and electric hoist. Control by telpherman.

By means of space-covering or movable telpher tracks coal can be deposited or removed from any portion of the storage yard, and not merely from beneath the telpher track. This track, movable by hand or electric power, greatly reduces the necessity of a multiplicity of telpher tracks and switches to serve all the space. The top surface of

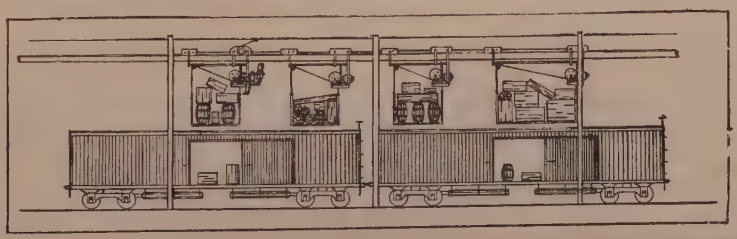


FIG. 7.—Side elevation of freight cars, telpher track, telpher and three trailers. One telpherman controls movement of train and hoisting and lowering of the loaded trucks.

the coal thus deposited is horizontal, and not in peaks, so that the whole vertical space can be utilized. Sand, gravel, earth, sulphur, or various chemical products can be as easily raised, transported, and dumped into vessels or cars.

Layouts.—Much engineering skill is required to lay out or plan the telpher lines for any proposed work in order to decide whether the

line should be single or double and the weight to be carried by each unit. The installations should be so planned that the expense will be reduced to a minimum, and, further, that the track will not interfere with existing machinery or buildings, taking care to avoid an excessive number of curves and switches, as these add more or less to the expense, particularly to the cost of erection.

Method of operation.—It is difficult to treat in a general way of the method of operation. In automatic lines it is necessary to provide appliances whereby it is impossible for an unskilled operator to injure the telpher. In order, therefore, to provide for contingencies, a "dead section" is placed at each end of the line, the middle of the line being generally left alive. Upon closing a spring switch, the dead section is energized so long as the operator keeps his hand on the switch, which is usually only a few seconds, during which time the telpher passes to that portion of the line which is always alive. When it reaches the other end it comes upon the dead section and then either slows down of its own accord, or else a mechanical or solenoid brake is applied. The telpher then passes under the reversing arrangement and it is therefore reversed, either with no current in the line or else with a high resistance. If the telpher is at the farther end of the line, the operator at the near end, by closing a switch, can bring it back to him. The dead sections at the end of the line, which have current only so long as the hand is held upon the spring switch, render the line as safe as possible against the telpher coming in contact with the terminal posts. An automatic block system prevents collision of telphers.

Curves.—The curves are solid rail and likewise the trolley track, where there is a curve, especially when it has a short radius. Wherever it is necessary to pass around a curve, to take turnouts or cross-overs, a resistance is inserted in the trolley circuit, whereby the telpher automatically reduces its speed while it is traversing the curve or turnout or approaching a cross-over switch. As soon as it reaches the other side of the curve it receives full voltage and continues at its normal speed. In regular service the speed varies from 300 or 800 feet per minute up to 20 miles per hour, or even more, when required. The slower speeds are used when the lines are short and where there are many curves, particularly for factory and foundry work. For lines running across the country a speed in excess of 20 miles per hour can be obtained, but with the higher speeds the cost of the construction increases, certain special devices being necessary. Even for installations which are termed "cross-country work," 15 to 20 miles per hour has been found amply sufficient.

As to what the ultimate capacity on grades may be, this has not been fully determined. Experimentally more than 20 per cent has been reached. In actual practice the greatest grade equipped has been 12 per cent, and thus far there seems to be ample traction.

Theoretical horsepower necessary to propel 1,000 pounds at various speeds and up various grades at same speeds.

Grades in per cent.	Speed in miles per hour.													
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	12.	15.	20.	25.
0	0.027	0.053	0.080	0.107	0.133	0.160	0.187	0.213	0.240	0.267	0.320	0.400	0.533	0.667
1	.053	.107	.160	.213	.267	.320	.373	.427	.480	.533	.640	.800	1.07	1.33
2	.080	.160	.240	.320	.400	.480	.560	.640	.720	.800	.960	1.20	1.60	2.00
3	.106	.213	.320	.427	.533	.640	.747	.853	.960	1.07	1.28	1.60	2.13	2.67
4	.133	.267	.400	.533	.667	.800	.933	1.07	1.20	1.33	1.60	2.00	2.67	3.33
5	.160	.320	.480	.640	.800	.960	1.12	1.28	1.44	1.60	1.92	2.40	3.20	4.00
6	.186	.373	.560	.747	.933	1.12	1.30	1.49	1.68	1.87	2.24	2.80	3.73	4.67
7	.215	.427	.640	.853	1.07	1.28	1.49	1.71	1.92	2.14	2.56	3.20	4.27	5.33
8	.241	.480	.720	.960	1.20	1.44	2.68	1.92	2.16	2.40	2.88	3.60	4.80	6.00
9	.267	.533	.800	1.07	1.33	1.60	1.87	2.13	2.40	2.67	3.20	4.00	5.33	6.67
10	.293	.586	.880	1.17	1.47	1.76	2.05	2.34	2.64	3.03	3.52	4.40	5.36	7.33
11	.320	.646	.960	1.28	1.60	1.92	2.24	2.55	2.88	3.20	3.84	4.80	6.40	8.00
12	.346	.693	1.040	1.38	1.73	2.08	2.43	2.77	3.12	3.46	4.16	5.20	6.93	8.67

Although the amount of power may be easily figured out, it is somewhat in the nature of a surprise when we consider that to carry half a ton on a level track at a speed of 6 miles per hour, much less than a horsepower is required, including all losses. This is a revelation to most manufacturers. The absence of gearing, the motors being attached directly to the driving wheels, gives the highest efficiency possible, as well as freedom from noise.

The actual power consumed, according to the table given above, at 6 miles per hour for 1,000 pounds on a level is only 0.16 horsepower. It is therefore seen that ample allowance is made for losses and extra weights not provided for in the load, such as down-comes, buckets, or carriers. The power required increases greatly with the grades, and when this reaches certain limits it is deemed advisable to use gears in order to reduce weight of motors.

Maintenance.—Although telpherage has not as yet been in operation for a sufficient number of years to determine exactly what the maintenance will be, yet, at the same time, in lines that have been operated for a year and a half the maintenance has been exceedingly small. As stated above, the driving wheels being of steel, none of them has thus far shown any signs of wear, and trailer wheels are of the same material and type which have been used on mechanical cable lines for ten years and are still in good serviceable condition. The motors, on account of their elevated position, have shown a better maintenance than stationary motors of the same type. This may possibly be from the extra care taken in their construction. In regard to the track, this has also shown most excellent results, also due to the fact that it is above grit and dirt and crossing teams and, when well painted, has shown little signs of wear or depreciation. Wherever a change is made from cable to solid rail or where cable passes over hangers or

brackets it is protected by what are called "shields," these being arranged so that they can be readily replaced. The cable is also protected at the hanger and brackets by steel shields.

Capacity.—An important feature in telpherage is the capacity of the line. In general, I can say that there is no other form of conveyor known which shows such flexibility. This is due to the use of electricity, and the features which apply to the street railway apply also to telpherage. There are two factors of special importance in relation to the capacity of the line: First, the speed, and second, the number of telphers and trailers. The line may be laid out with one

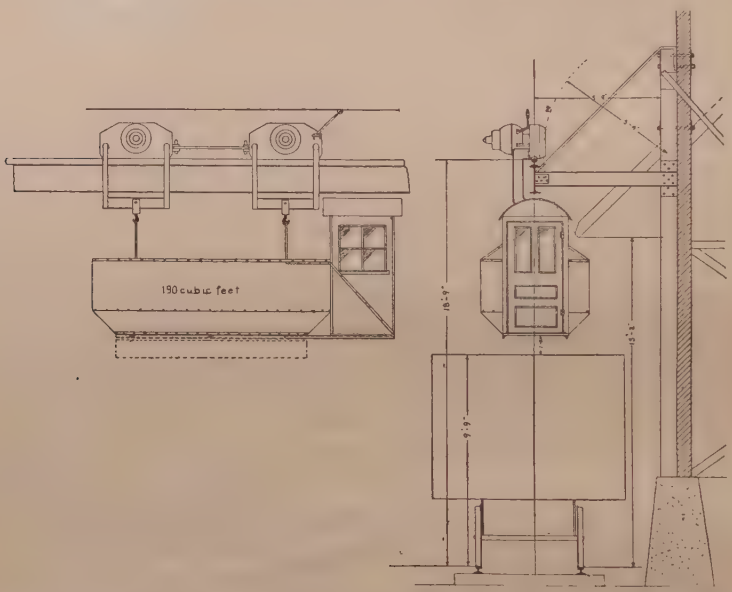


FIG. 8.—Plan and elevation of another form of double telpher with 4-ton coal bucket, bottom dumping, cab for telpherman. The side elevation shows method of attachment to side of building and loading chute.

telpher and a few trailers. More telphers or trailers may be added, and, if upon a single line, coupled in long trains. If it is desired still further to increase the capacity, the line may be made double, while, if desired, the carriers may also be made continuous so as to take boxes and barrels or other freight as fast as they can be delivered to the carriers of the telphers and trailers.

The flexibility of telpherage in regard to capacity is wonderful, and is a most important feature. In fact, it may be said that there is practically no limit to flexibility. In one plant, about to be installed, the proposed capacity is 250 tons per hour, over a distance of one-half a mile, the material to be distributed over an area of about an acre. Anyone who is familiar with conveying will note that there is no

other system that can do this so economically, cheaply, and in a way so thoroughly satisfactory a manner as telpherage.

The nature of installation varies with the amount of material to be carried, so that if the amount to be carried is small, the expenditure need not be great.

Applications of telpherage.—There are few factories where the installation of an overhead telpherage system would not prove a valuable investment. The question is often asked: Is telpherage suited for carrying specific articles? And the reply may be that it is adapted to the conveying of the products of almost every kind of manufacturing.

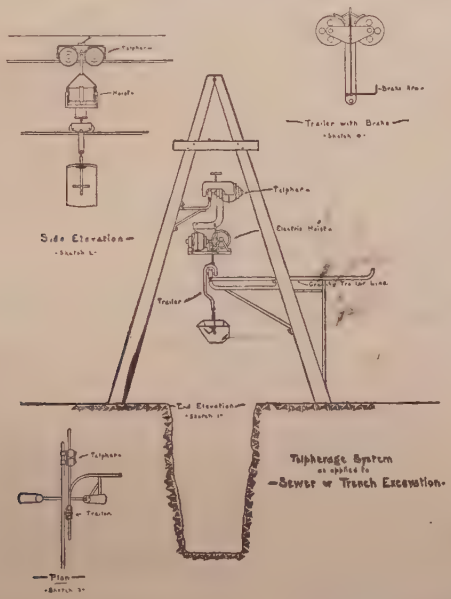


FIG. 9.—In sewer or trench excavation the method of operation is as follows: The bucket has attached to it a trailer wheel. The buckets and wheel are lowered into the excavation and the bucket, when filled, is raised by the electric hoist so that the wheel of the trailer engages the gravity rail. The load then passes by gravity to the place desired and is automatically dumped. This may be along the line of excavation, for refilling the trench, or to the right or left, for unloading into carts, or in connection with the telpher to any desired distance. The telpher has the flexibility of a trolley car. This method is a combination of telpher and gravity lines, and the amount of work that can be accomplished by it with the minimum of labor is remarkable.

In these days of consolidation of companies, factories cover immense areas. The individual buildings are frequently large enough in themselves to utilize a telpher line. In many cases, on account of fire risks or of convenience in manufacturing, the buildings are widely separated from each other, and yet constant communication is necessary. Overhead telpherage, therefore, in manufacturing establishments is used for carrying the raw material, implements, and finished products from one part of the grounds to another, from one building to another, or even from one part of a building to another part, moving raw material from cars or vessels to the works and then taking the finished products

to the railway station or the wharf for shipment, and for conveying refuse away from the factory. In this connection we might mention the conveying of ashes or slag to the dump heap.

Telpherage may also be extensively used for handling coal. It serves to reduce greatly the cost of transportation on plantations and farms and may be economically used for handling coffee, sugar cane, tobacco, fruits, and hay and other like products.

In general, it may be said that wherever material is to be carried to a distance there is no power so flexible, so economical in first cost of installation, costing so little for power or the expense of maintenance, and with such great capacity as telpherage. It may, therefore, be designated a material transportation by an immaterial fluid, and may well be called one of the most important of the many adaptations of electricity.

If time, floor space, or labor is being consumed in the conveying of

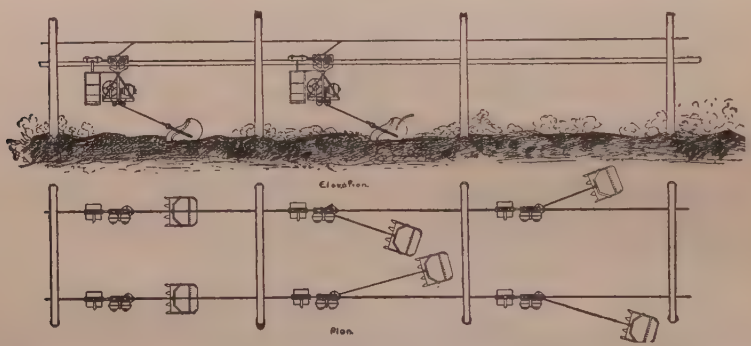


FIG. 10.—Excavating and leveling in preparing roadbeds for railroads. The function of the telpher is to transport the hoist, bucket, and load. The hoist does the excavating and elevating. The hoist automatically brakes itself either upon the girder rail or grips the cable as soon as there is any longitudinal strain. Used also for scooping and transporting earth, sand, ashes, or coal.

any kind of material in any plant, plantation, or mine, each can be saved by the installation of telpherage. Any condition at any manufacturing establishment which presents a requirement for hauling by man or team, whether in transmission of product during the various stages of manufacture, the movement of materials by which the product is to be treated, or the handling of fuel and ashes or other waste, is a logical opening for the installation of telpherage.

When you install telpherage you employ a machine to do the work of men. Machinery is the most powerful factor for economy in production. Telpherage is almost human in its operation, works any number of hours per day, and never tires. In many cases you start the telpher, it conveys, automatically leaves its load at the destination, and returns for another load. Telpherage conveys 50 pounds or 50,000 pounds, solids or liquids.



CONVEYING COAL FROM REMOTE SHEDS TO BOILER ROOM AND GAS HOUSE—HIGH TELPHER LINE OVER ROAD.

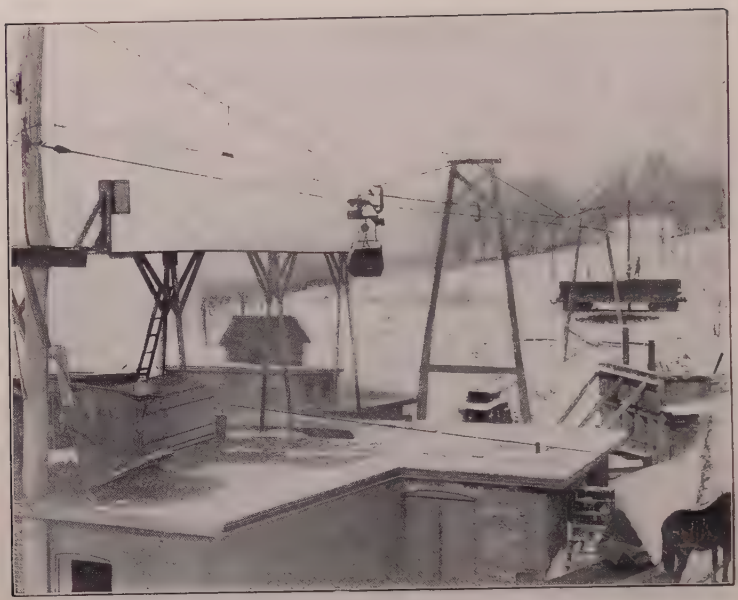


FIG. 1.—COAL FROM CAR ON SIDING ACROSS THE RIVER TO THE POWER STATION.



FIG. 2.—CARRYING COAL FROM STORAGE SHEDS TO GAS WORKS.



FIG. 1.—HOGSHEADS OF SUGAR FROM THE SIDE OF VESSEL TO WAREHOUSES.



FIG. 2.—TELPHER, TRAILER, AND MINIMUM HEADROOM HOIST.

Automatic line for ashes, coal, or coke.



FIG. 1.—TELPHER, TRAILER, ELECTRIC HOIST, WITH PLATFORM CARRIER.



FIG. 2.—AMTOMATIC LINE IN PAPER MILLS—PAPER PULP.



FIG. 1.—CURVE CONSTRUCTION OF CABLE TRACK WITH HEAVY LOAD.

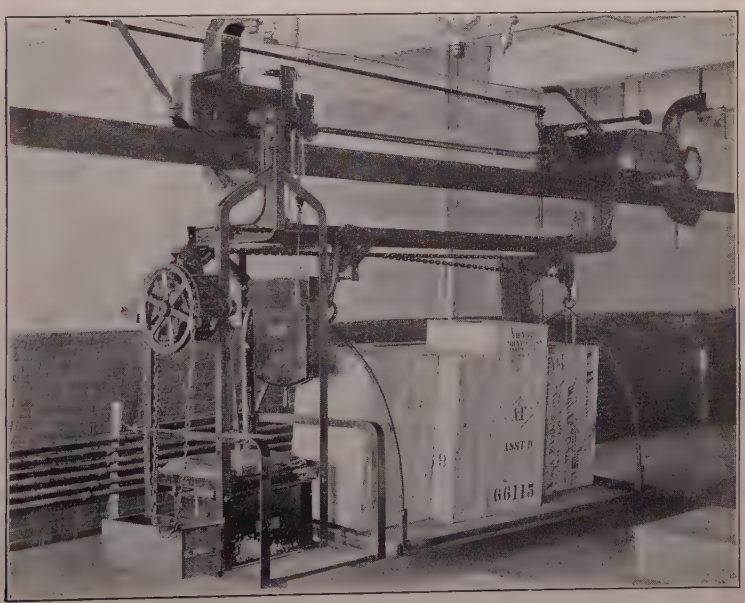


FIG. 2.—TELPHER AND TRAILER WITH PLATFORM CARRIER LOADED WITH CASES OF DRY GOODS.



LOAD WITH BUCKET, 3 TONS; SPEED, 1,000 FEET PER MINUTE.

Applicable to coal, gravel, sand, and like divisible material. Telpher for conveying, double-drum electric hoist for elevating, lowering, opening, and closing clam-shell bucket. Electricity does the work of 18 men, one man directing.

THE EVOLUTION OF PETROLOGICAL IDEAS.[a]

By J. J. Harris Teall, Esq., M. A., V. P. R. S.

INTRODUCTION.

The nineteenth century, whose obsequies we have so recently celebrated, was born in what has been aptly termed by Professor Zittel, our latest historian, the heroic age of geology. Geological societies and geological surveys did not then exist. Cooperative work was unknown; but a few individuals, of great power and originality, were laying the foundations of our science on a firm basis of accurate observation. Pallas had recently carried out his remarkable researches in eastern Russia, and had noted the extraordinary abundance of the remains of the mammoth, rhinoceros, and bison in the superficial deposits of the Siberian plains. De Saussure had climbed Mont Blanc, and published his unrivaled descriptions of Alpine scenery and Alpine structure. Werner was still acting as an exponent of the science which he had done so much to foster, and had fired his two most illustrious pupils, L. von Buch and Humboldt, with that enthusiasm for natural knowledge which was destined to produce such glorious results. Hutton had just passed away, after giving to the world his Theory of the Earth, the main features of which form the basis of modern geology. Smith and Cuvier, both born in the same year (1769), were in the prime of life, and actively engaged in those researches which placed stratigraphical geology on a secure foundation. These are some of the heroes of our science.

The early history of geology is mainly a record of fantastic speculations; but in the heroic age it was beginning to be recognized that no solid advance could be made except on a basis of carefully observed fact. A reaction against the wild speculations of the seventeenth and the greater portion of the eighteenth centuries had set in, and this led, among other things, to the foundation of our society—the parent of all such societies—in 1807.

[a] Reprinted by permission of the author and of the society from Proceedings of the Geological Society, London, vol. LVII, pp. lxii–lxxxvi, May, 1901. Anniversary address of the president of the society.

That it was necessary to put a curb on the unbridled license of geological speculation, and to emphasize the importance of diligence and accuracy in the observation of facts, will be admitted by all students of the history of our science; but it is well to remember that there is a scientific, as well as an unscientific, use of the imagination. The chief glory of science is, not that it produces an amelioration of the conditions under which we live, but that it continually enlarges our view, introduces new ideas, new ways of looking at things, and thus contributes in no small degree to the intellectual development of the human race.

It is now generally recognized that the state of advancement of a science must be measured, not by the number of facts collected, but by the number of facts coordinated. The old Baconian idea that it was only necessary to collect facts and pigeonhole them according to rule, in order to make the most brilliant discoveries, has been somewhat discredited by the history of scientific progress. Speaking on this subject, De Morgan says:

"Modern discoveries have not been made by large collections of facts, with subsequent discussion, separation, and resulting deduction of a truth thus rendered perceptible. A few facts have suggested an hypothesis which means a supposition proper to explain them, the necessary results of this supposition are worked out, and then, and not till then, other facts are examined, to see if these ulterior results are found in Nature. * * * What are large collections of facts for? To make theories from, says Bacon: to try ready-made theories by, says the history of discovery; it's all the same, says the idolater; nonsense, say we."

Hutton appears to have been of De Morgan's way of thinking. He pondered over the facts that he had observed in England, France, and Scotland, and formulated his theory of the earth. He then went again into the field to test the consequences of his theory, and verified them. He never seems to have thought it worth while to describe isolated facts, or the structure of particular districts, except in so far as they illustrated his theory, although no one was better qualified to do this, as all readers of his description of the unconformity at Siccar Point, of the granite veins in Glen Tilt, or of the geological features of Arran will readily admit. His joy at the discovery of the granite veins in Glen Tilt can be easily understood. His theory required that they should exist, and they were found, not by chance, but because they were looked for. And we may be sure that the joy did not arise from gratified vanity, for, as Playfair says, he was one of those who took more delight in the contemplation of truth than in the praise of having discovered it.

In thus calling attention to the importance of ideas in scientific research, I trust it will not be thought that I am advocating a return to the condition of things which prevailed in the early days of geolog-

ical history. Armchair philosophizing, apart from actual work in the field, the laboratory, and the museum, is by no means to be commended. But the worship of fact, as fact, may easily be overdone. The number of discoverable facts is practically infinite, and it is therefore possible to get into such a condition as not to be able to see the wood for the trees, to lose the due sense of proportion, and to become mere machines for tabulating interminable trivialities.

On the other hand, it should be remembered that every worker endowed with imagination must formulate, in his own mind, many theories that will not stand the test of verification, and that it is quite unnecessary for him to trouble other workers with such theories. He can test them for himself, and relegate them to oblivion if necessary, without burdening our overcrowded bookshelves with crude speculations and unverified hypotheses.

It is only when a theory has proved its usefulness as a coordinator of fact that it becomes worthy of the dignity of publication. It may be true or false, most likely the latter; but if it coordinates more facts than any other it is at any rate useful and may be conveniently retained until replaced by a better. Controversy as to the truth or falsity of a theory often seems to me beside the mark, for if a given theory coordinates more facts than any other it is at least worthy of respect, and may be tentatively held as a working hypothesis, along with the conviction that it is not true, or only partially true. Indeed, the controversial spirit is, in my judgment, inimical to the best interests of science. It makes a man more eager to refute than to understand the views of his opponents; it tends to check the flow of sympathy, and thus often prevents that friendly cooperation which is so desirable in the interest of scientific progress. When controversy becomes acute, I always feel inclined to exclaim "a plague on both your houses."

Every branch of our many-sided science has benefited by the zeal for collecting facts which manifested itself during the early years of the nineteenth century. Methods of observation have been perfected, national surveys and private individuals have examined and are examining the geological structure of every civilized State, and explorers have penetrated to almost every quarter of the globe. Our libraries and museums are being rapidly filled with records of all this scientific activity. Side by side with the registration and cataloguing of facts there has taken place an evolution of scientific ideas, and it is on this aspect of the subject, so far as my own special branch is concerned, that I propose to offer a few remarks.

Rocks may be studied from two more or less distinct points of view, the descriptive and the aetiological. But it is well to note that the distinctness of these two points of view is but the expression of our ignorance as to the genetic relationships of the different types. Facts

as to composition, structure, and the like, accumulate faster than they can be interpreted; and our classifications are therefore necessarily more or less artificial. But there is that within us which compels us to bring our classifications into accord with our views as to genesis. Phylogeny must in the end control classification both in the organic and inorganic worlds. As soon as we realize that any scheme of classification places together objects which have no genetic relationship, or groups them irrespective of such relationship, we become dissatisfied with it. The old classifications need not be thrown over the moment that their imperfections are glimpsed; but in the end they have to be discarded, and the new ideas find expression in a new classification. Thus

> Thro' the ages one increasing purpose runs,
> And the thoughts of men are widened with the process of the suns.

How far Hutton was in advance of his time on matters relating to petrogenesis is illustrated by the fact that more than half a century elapsed before his ideas found expression in systematic treatises. Yet the separation of rocks into igneous, sedimentary, and metamorphic, and the further subdivision of the igneous rocks into plutonic and volcanic, follow naturally and logically from his fundamental conceptions.

The reason for the tardy recognition of what is now generally admitted to be the true basis of classification is not far to seek. Hutton was no systematist. Werner, on the other hand, was not only a keen observer, but he possessed in quite an exceptional degree the power of describing what he observed in precise and definite terms and of grouping his facts according to their supposed relationship. He was, in short, a born systematist, and this, combined with his eloquence and enthusiasm, gave him a commanding influence. In looking back at these two striking figures of the heroic age, Werner and Hutton, it is almost impossible to avoid a feeling of regret that the one did not possess what the other lacked. But such regrets are useless. Let us honor them both.

The authors of systematic treatises on rocks published during the first half of the century were all under the spell of Werner, and they were still further hampered by their ignorance of the composition of those rocks which are of so fine a grain that their constituents can not be determined with the naked eye or with the aid of a simple magnifying lens. The treatises of Haüy, Brongniart, and Leonhardt clearly recognized the great natural group of fragmental rocks; but the true limits of the other equally natural groups were, so far as general treatises are concerned, brought into prominence for the first time in the work by Von Cotta, the English translation of which appeared in 1866.

PROGRESS DURING THE FIRST HALF OF THE CENTURY.

Igneous rocks played but a small part in the Wernerian system. They were regarded as stratified rocks melted by heat, due to the burning of coal beneath volcanic districts. We now recognize that they are of great importance, and probably represent the original source of all the other rocks. The clearing up of our ideas as to their nature and mode of origin centers round two controversies—one as to the origin of basalt, the other as to the origin of granite.

It is difficult for us to realize the condition of things which prevailed during the early years of the century, when the martial spirit of the age seems to have affected the scientific world and a furious controversy raged between the Neptunists and the Vulcanists as to the origin of basalt. We look with a feeling of astonishment at the controversialists, condemn their methods, and admire the calm figure of the old man Desmarest as he sits there refusing to be dragged into the controversy, and quietly replies to his challengers, "Go and see." Now and again, in looking through some neglected cabinets of our museums, we come across dust-covered specimens labeled "Ammonites in basalt from Portrush," and are thus forcibly reminded of those stirring times.

The controversy as to the origin of granite lasted longer, and during its later stages, at any rate, was conducted with dignity and a due regard to the amenities of scientific discussion. It resulted, moreover, in a very decided enlargement of our conceptions as to subterranean phenomena. The Wernerian view that granite was a precipitate from a primordial ocean was compelled to give way as soon as the tectonic relations of granitic masses, so well described by Hutton, Playfair, and Sir James Hall, were clearly realized. The phenomena of granite veins, the occurrence of inclusions of the surrounding rocks, and the sharpness of the junctions between granite and the strata with which it is in contact prove beyond all doubt that the material of which many granite masses are composed must have been intruded from below in a plastic state. Toward the middle of the century these facts were generally recognized for all those masses which occur outside areas of crystalline schist. But their recognition, although conclusive as against the view that granite was everywhere a primordial sediment, by no means involved the necessity of accepting the Huttonian theory that it resulted from the consolidation of a mass of matter in a state of pure igneous fusion.

The earlier phases of the discussion as to the origin of granite centered mainly round the tectonic relations of the rock masses; but the later phases had reference rather to the composition and structure of the rock itself. The papers on this subject, and especially the discussion between Scheerer and Durocher, are well worthy of the attention of modern petrologists.

Scheerer maintained that the purely igneous origin of granite was disproved by three lines of argument. Thus he contended that the very presence of quartz was opposed to the theory, for this mineral could not be formed by igneous fusion, and was absent from lavas containing an excess of silica, such as obsidian, even when these lavas must have cooled more slowly than some granite veins.

Again, the order of consolidation of the minerals, as determined by mutual interference, was not the order of their fusibilities. Fournet had endeavored to remove this objection by supposing that quartz, like water and sulphur, could be cooled below its proper melting point. But this theory of the surfusion of quartz was untenable, because the amount of overcooling was too great and the complete rest which was necessary could not be postulated. Scheerer admitted that the objections to Fournet's theory were rendered less forcible by a consideration of the fact pointed out by Durocher, that the magma of granite did not contain the material of the separate minerals in a fused state, but consisted of a homogeneous liquid — a solution as we should say — so that the overcooling did not affect quartz as such. This, however, in his opinion, did not justify the theory, for, to use a free translation of his own words: "It is evident that the point of solidification of the silicate forming the magma out of which the different compounds are separated ought to approach the fusion point of silica as the quantity of bases in the liquid portion decreases."

According to Durocher's view, the ultimate base of granite should consist, not of quartz, but of a substance like petrosilex.

A third line of argument, founded on the occurrence in some granites of the peculiar pyrognomic minerals, such as gadolinite, was also brought forward by Scheerer. If a chip of isotropic gadolinite be heated to redness, a sudden and remarkable change takes place. It glows brightly for a few moments, and after cooling is found to have become denser and strongly birefringent. Thus gadolinite occurs in two phases; a lighter isotropic phase and a denser birefringent phase. The change from the former to the latter takes place at a red heat, and the reaction is accompanied by a considerable loss of energy, but little or no loss of material. The occurrence of this mineral in some granites proves, therefore, according to Scheerer, that they must have consolidated below a red heat.

These three lines of argument, based on the presence of quartz, on the mutual relations of the constituents, and on the presence in some granites of pyrognomic minerals, concur, he considers, in disproving the theory of pure igneous fusion.

Scheerer then propounds his own theory of aqueo-igneous fusion, basing it on the fact that some of the granitic minerals, such as mica, contain water. The presence of even small quantities of water would, he maintains, lower the consolidation point considerably, and during

consolidation the water would concentrate in the mother liquor, and ultimately in the silica. Final consolidation would take place on the escape of the water. Thus the paradoxical order of crystallization would be explained, and the granite might consolidate at a temperature which would admit of the formation of the pyrognomic minerals.

The theory of Scheerer was opposed by Durocher, and the controversy between these two distinguished men extended over a period of three or four years. Durocher considered that a close examination of the structure of granite does not bear out the view that there is a well-defined order of consolidation. The minerals mutually interfere one with the other, sometimes one and sometimes another having the advantage. The magma appears to have cooled down to a comparatively low temperature, and then to have separated into definite compounds which did not solidify instantaneously. The relative perfection of form would, on this view, be largely determined by the relative power of crystallization of the different constituents. In this respect quartz is at a disadvantage. It possesses, moreover, as shown by M. Gaudin, a great range of viscosity, and when fused can be drawn into threads like glass and sealing wax. He agrees with Scheerer in rejecting Fournet's theory of surfusion, and considers that the paradoxical order of consolidation can be explained by taking into consideration the wide range of viscosity of quartz and its slight tendency to crystallize. A similar view has recently been advocated by Professor Joly. Durocher replies to Scheerer's argument derived from the absence of quartz in obsidians by pointing to its presence in trachytes, and attempts, somewhat unsuccessfully, to explain away the presence of the pyrognomic minerals. In his criticisms of Scheerer's views as to the amount of water present in granite he is often effective, for he shows that sufficient allowance had not been made for the effects of alteration.

Scheerer's view became the popular one, and is now generally held. It was greatly strengthened by Dr. Sorby's discovery of the widespread distribution of liquid cavities containing water in the quartz of granites, and by the well-known synthetic experiments of Daubrée and others. The failure of all attempts to produce granite is also still felt to be a strong argument against the theory of dry fusion.

Scheerer concludes the discussion with some observations which I can not refrain from quoting. He says:

"To avoid misunderstanding, I desire to make some remarks on the value which I attach not only to my theory of the origin of granite, but also to geological theories in general. I am far from believing that the igneous theory, which M. Durocher defends with so much vigor, is finally disposed of, or that my theory is completely satisfactory. Such definite conclusions can not be reached in the present state of our science. More than one point of view is possible on almost every subject of this kind, and thus it must ever be, for mathematical certainty is unattainable.

"A short time ago it seemed as if the Neptunean theories had completely abandoned the field in favor of those volcanic theories which appeared so absurd to our ancestors. Now the Neptunean theories are beginning to show signs of life. I have endeavored to conciliate the two sister enemies by suggesting that water may play an important part in the formation of fused rocks. * * * I do not pretend, however, that my theory is unassailable, or that it has been absolutely demonstrated. * * * In my opinion a geological theory should not be considered as absolute; but it becomes probable when a considerable number of facts group themselves around it, and its degree of probability can be measured by its power of assimilating the new facts brought to light by the progress of science."

These are wise words, and may well be remembered when differences of opinion tend to become sharply accentuated. The path of science is littered with discarded theories, and this fact should serve to remind us that "we are none of us infallible, not even the youngest."

In the discussion between Scheerer and Durocher attention was directed to the mutual relations of the constituents of granite and to the inferences which could be drawn from a study of those relations as to the order of consolidation of the minerals.

THE CONSOLIDATION OF IGNEOUS MAGMAS.

At the time when the discussion took place this kind of reasoning could be applied only to coarse-grained rocks, but with the advent of the microscope it became possible to extend it to the important group which had been designated in the earlier classifications as "apparently homogeneous rocks." In the early part of the century Cordier had proved, by the microscopic examination of the powder of basalt, that this rock was heterogeneous; but it was not till the examination of thin sections had been introduced that the mutual relations of the constituents of the finer-grained rocks could be studied. In those rocks which have resulted from the consolidation of homogeneous silicate magmas, and in which the consolidation has been unaccompanied by the phenomena of resorption—that is, in which there has always been equilibrium between the constituents during the process of consolidation—the order of separation can be inferred from the microscopic structure.

It has thus been established that the process of consolidation can not be divided into a number of sharply defined periods, each characterized by the separation of some one mineral only, but that the times during which the different minerals are separating out overlap to some extent. The amount of overlapping varies in different cases, and in one and the same magma is most marked in plutonic masses; whence we conclude that it is largely determined by physical conditions, and especially pressure.

The order of consolidation as determined by an examination of the mutual relations of minerals is, therefore, the order in which they com-

mence to form, and this order may or may not agree with that in which they cease to form. The laws which express the order of formation of minerals and the chemical and physical conditions which control that order have not as yet been definitely established.

One of the most important papers on theoretical petrology is undoubtedly that by Professor Rosenbusch on the significance of the granular and porphyritic structures in massive rocks. The importance of this paper must not be judged simply by the amount of truth in the principles enunciated, but rather by the stimulus which it gave to theoretical considerations and to researches directed toward a particular end. The constituents of massive rocks are divided by Professor Rosenbusch into four groups:

1. The ores and accessory constituents (magnetite, hæmatite, ilmenite, apatite, zircon, spinel, and titanite).
2. The ferromagnesian constituents (biotite, hornblende, pyroxene, and olivine).
3. The felspathic constituents (felspar, nepheline, lucite, melilite, sodalite, and haüyne).
4. Free silica.

Professor Rosenbusch pointed out that members of the first group precede those of the other groups; that in granites and syenites the members of the second group precede those of the third; but that in the diabases and gabbros the order is inverted, and that in both groups silica is the last. The general conclusion is reached that "the order of consolidation of the silicates and, consequently, their crystallographic development (idiomorphism), corresponds to a law of decreasing basicity; the ores and accessory minerals are the earliest, and quartz is the latest, product of the rock-forming process."

This empirical law expresses, in a broad and general way, the main facts observed with regard to the sequence of minerals in the large and important group of intermediate rocks, but it breaks down when applied to the most acid and the most basic rocks; quartz is often formed before felspar in the former, and iron ores are not infrequently formed after felspar in the latter.

The views that we hold regarding the laws which express the order of consolidation in igneous magmas will necessarily be colored by our conceptions as to the nature of these magmas. A great advance in the evolution of ideas on this subject is marked by a short letter, written by Bunsen to Streng, and published in the Journal of the German Geological Society for 1861. In this letter Bunsen points out that the arguments against the igneous origin of granite, so far as they rest upon the so-called anomalous order of consolidation of the minerals, are based on a misconception of the nature of the process of consolidation. He says:

"The temperature at which a substance consolidates from a state of fusion is never that at which it separates from a solution in another

substance. The temperature at which a definite substance crystallizes from its own liquid depends only on the substance and on the pressure to which it is subjected; whereas the temperature at which the same substance separates from its solution in another substance depends principally on the relative proportions of the two substances. No chemist will fall into the error of assuming that a solution ceases to be a solution at 200°, 300°, 400°, 500°, or even when heated to a temperature at which it becomes self-luminous; or will suppose that a crystalline aggregate of ice and calcium chloride which has become fluid is a solution, but that a mixture of quartz and felspar which has been fused is not."

He then proceeds to point out that the laws which govern the solidification of aqueous solutions must hold good also for igneous solutions; that by the addition of a certain amount of calcium chloride to water the temperature may be lowered to −10° C. without the separation of any solid substance; that by the addition of further amounts the temperature of consolidation of water may be lowered as much as 59° and that of calcium chloride 100°. Other salts, such as the sulphates and nitrates of potassium, may be made to separate from aqueous solutions at temperatures from 600° to 800° below their freezing points; moreover, the order of consolidation is determined by the relative amounts of the two substances present; thus water may be made to consolidate before or after a dissolved salt by varying the concentration of the solution.

I have given a somewhat full abstract of this important letter because I believe that the expansion of the idea which it contains will be the characteristic feature of the next great advance in petrological science, an advance which will come about, not so much by adding to our already large store of facts as by dint of experiment controlled by the modern theory of solution, and carried out for the express purpose of testing the consequences of that theory and discovering the modifications which may be necessary to adapt it to igneous magmas.

Almost all recent writers on theoretical questions relating to the igneous rocks have accepted the solution theory, and the condition of formation of minerals has been discussed from this point of view. Crystals tend to form in a homogeneous liquid mass when the liquid becomes supersaturated with any definite compound. As soon as crystals are developed the liquid in their immediate neighborhood ceases to be supersaturated, and there is thus established an osmotic force producing molecular flow from the supersaturated portions toward the growing crystals.

From a consideration of the work of Pelouze on glasses, combined with his own work on igneous rocks, Lagorio arrived at the conclusion that the ordinary rock-forming compounds tend to separate out in the following order: Oxides, pure iron silicates, magnesian and ferro-magnesian silicates (olivine and rhombic pyroxenes), calc-magnesian silicates (monoclinic pyroxenes and hornblende), silicates of magnesium

and potassium or of iron and potassium (biotite), calcium silicate (anorthite), silicates of sodium and calcium (plagioclase), sodium silicates (nepheline and albite), and lastly, potassium silicates (orthoclase) in conjunction with quartz.

In his important work on slags, Professor Vogt has clearly established the influence of the relative proportions of the bases to each other and to silica in determining the nature of the compounds which separate out. Thus in slags in which the ratio of bases to silica corresponds approximately to that found in bisilicates the ratio of CaO:MgO determines the formation of such minerals as enstatite, augite, and wollastonite. When the ratio of MgO+FeO : CaO is greater than 2.44 : 1, enstatite forms; when the same ratio is less than 1.4 : 1, augite separates out, and continues to do so until this ratio becomes less than .35 : 1; with a still further diminution in the ratio of magnesia to lime, wollastonite is formed.

In slags having approximately the composition of monosilicates the ratio of MgO+MnO+FeO : CaO determines the formation of olivine or melilite. When the above ratio is greater than 1 : 1.1 (in slags with about 20 per cent of alumina), olivine is formed; but when it is less than 1 : 1.25, melilite is produced.

The general conclusion arrived at as a result of the work of Vogt, Lagorio, and others is that mass action and the affinities of the bases to each other and to silica are the two factors of primary importance in determining the molecular grouping, so long as the pressure remains constant. The action of alumina may be especially referred to as illustrating the influence of the mutual affinities of the so-called bases. In the sorting of partners in accordance with the law of mass action this substance, when present in sufficient quantity, practically takes the whole of the alkalies and as much of the lime as is necessary to make felspathoid molecules. So marked is this action that M. Michel-Lévy and M. Osann, in calculating the results of analyses, combine the whole of the alumina with the alkalies, when the latter are present in sufficient quantity, and associate any excess of alumina with lime in the form of felspathoid molecules. It is only in those rocks that contain an abnormal percentage of alkalies that minerals like ægirine and riebeckite occur.

This controlling influence of alumina, which has also been emphasized by Professor Iddings, has the most far-reaching effects in determining petrographical species. It is as if there were a kind of repulsion between the ferromagnesian and alumino-alkaline constitutents. Dark rocks rich in the former, and light rocks rich in the latter, represent the extreme forms of many intermediate types; and Professor Brögger has recently proposed that this should receive expression by

the application of the terms melanocratic and leucocratic to these two strongly contrasted varieties.

The results already obtained leave no doubt that a properly directed series of experiments will throw great light on the laws which control the formation of minerals during the consolidation of igneous rocks. The classic researches of Professor Fouqué and M. Michel Lévy on the synthesis of such rocks as basalt, andesite, and nephelinite by pure igneous fusion show that we can control the necessary physical conditions, and that the whole subject, so far at least as these rocks are concerned, lies within the range of experiment.

The work of Morozewicz, to which I have directed attention in another place, may be mentioned as proving that a rich harvest of results may be confidently anticipated from experimental work in this direction.

To return to the question of the order of consolidation of minerals in igneous rocks. If the solution theory be true, no order based solely on a consideration of the properties of the minerals can hold good in all cases. In the case of aqueous solutions of two substances the order of separation, as pointed out by Bunsen, depends on the relative proportions of these two substances. This subject, so far as alloys, fused salts, and aqueous solutions are concerned, was investigated with great skill by Professor Guthrie, the importance of whose work on alloys has been brought into prominence of late by the researches of Roberts-Austen, Le Chatelier, Osmund, J. E. Stead, Heycock and Neville, Alder Wright, and others.

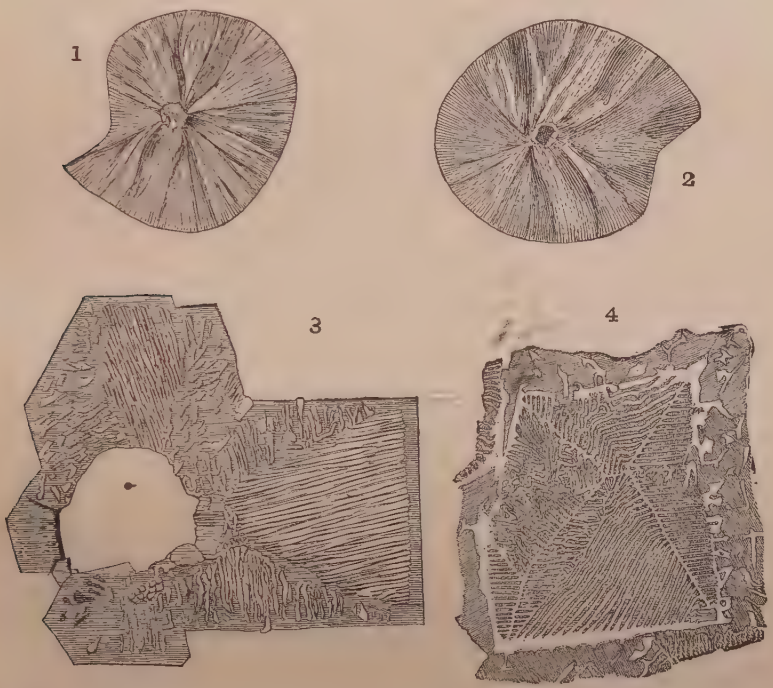
It is too early yet to discuss the full bearing of this recent work on petrographical questions, but it is impossible to examine the beautiful photographs which illustrate the structure of alloys—such, for example, as those accompanying the fifth report of the alloys research committee,[a] or those illustrating Stead's paper on iron and phosphorus,[b] or Heycock and Neville's paper on gold-aluminium alloys,[c] without being struck by the resemblance of many of these structures to those met with in rocks.

Some years ago I directed attention to the possible application of Guthrie's work on cryohydrates and eutectics to petrographical questions, and the experience since gained has tended rather to confirm me in the views which I then expressed. Fused salts which do not act chemically upon each other show, when mixed in eutectic proportions, a marked tendency to form spherulitic, and what may be called micropegmatitic, intergrowths. It has since been proved that the same is true of alloys. Thanks to the kindness of Mr. J. E. Stead, I am able to give two figures, drawn from photographs, which illustrate this

[a] Fifth Report by Sir William Roberts-Austen, Proc. Inst. Mech. Eng. 1899, p. 35.
[b] Journ. Iron and Steel Inst., vol. lviii (1900) p. 60.
[c] Phil. Trans. Roy. Soc., vol. cxciv (1900) A, pp. 201–232.

fact, and side by side with these are placed figures of micropegmatitic and spherulitic structures copied from Professor Iddings's memoir on the rocks of Obsidian Cliff. (Figs. 1–4.)

In the case of the alloys the spherulitic structures are characteristic of rapid cooling and the micropegmatitic structures of slow cooling. The mode of occurrence of the same structures in rocks is strictly in accordance with this view. A comparison of the structures in the two cases makes it almost impossible to believe that the resemblances



FIGS. 1 and 3 = Spherulitic and micropegmatitic structures in obsidian. (After Iddings, VIIth Ann. Rep. U. S. Geol. Surv., 1885–86, pl. xv.)

FIGS. 2 and 4 = Similar structures in eutectic alloys; from microphotographs by Stead. 2 = A simple spherulite in the eutectic of lead and antimony;[a] 4 = Micropegmatitic structure in magnolia-metal (lead, 80 per cent; antimony, 15 per cent; and tin, 5 per cent).

are merely accidental, and, if not, they point to the conclusion that micropegmatite is an eutectic compound.

From this point of view it becomes of interest to determine the melting point of fused micropegmatite. This was kindly done for me by Professor Joly by observations with the meldometer. He found that fused micropegmatite melted somewhat more readily than orthoclase, but less readily than fused orthoclase. These observations do not support the eutectic hypothesis, but they can scarcely be said to

[a] The outlines of this spherulite are somewhat too sharply drawn.

negative it, as the conditions of the experiment are certainly very different from those under which the rocks are produced.

Quartz and orthoclase have not as yet been formed by pure igneous fusion. The melting point at atmospheric pressure of a mixture of quartz and orthoclase is above that of basalt, and yet we know from the occurrence of angular fragments of basalt in granophyre that the consolidating point of the mixture under certain conditions of pressure is below that of the fusing point of basalt under the same conditions. If, as Professor Lœwinson-Lessing's calculations suggest, the formation of felspathic minerals is accompanied by an increase in volume, and the formation of ferro-magnesian minerals by a decrease in volume, pressure will lower the fusing point of the former and raise that of the latter, so that under plutonic conditions the relative order of consolidation of acid and basic magmas may be the reverse of that under volcanic conditions. Magmas usually contain water, and sometimes other volatile constituents (such as chlorine, boron, fluorine, etc.), whose importance in determining the fluidity and the molecular grouping of the constituents has been generally recognized since the publication of the classic paper "Sur les Emanations Volcaniques et Métallifères," by Elie de Beaumont. When separated from the magma these constituents exercise most important metamorphosing and mineralizing effects, as is well seen in the phenomena accompanying the formation of tinstone and apatite veins, in the development of zeolites, and in the production of large masses of kaolin. But so long as they remain in the magma they must be regarded as belonging to it and playing their part along with the other constituents in producing the final result.

The application of the theory of solutions to igneous rocks is complicated in many ways. We are ignorant of the manner in which the constituents revealed by analysis are distributed in the molten magmas, and of the changes which take place in the molecular groupings as the temperature approaches the point of saturation. M. Le Chatelier has recently suggested that granite furnishes an illustration of the phase rule, and may be regarded as a stable system of three phases (quartz, feldspar, and mica), made up of the three components—silica, alumina, and potash. Few petrographers will admit that the case can be put as simply as this. No doubt the consolidation of igneous magmas is governed by the phase rule, but in the majority of cases the number of components, on any view as to their nature, is too great to make the rule of much practical value. Another cause of complication arises from the fact that the physical conditions have often changed during the process of consolidation, thus giving rise to the phenomena of resorption; and yet another from the absence of assurance that the minerals seen in a rock have in all cases been developed from a magma having the composition represented by the bulk analysis.

I can not leave this portion of the subject without calling attention to the recent work of Professor Joly on the melting points of the rock-forming minerals, and his proof of the enormous range of viscosity possessed by quartz and other minerals.

Whatever view we take as to the nature of silicate magmas, there can be no doubt that in general the process of consolidation is a process of differentiation. Definite compounds separate out, either successively or simultaneously, from a homogeneous magma, and at the time of their formation are in equilibrium with the surrounding liquid; but owing to changes in temperature and pressure the equilibrium established at one period may be destroyed at another, and the igneous rock as we see it may not contain a record of all the operations which have taken place during the process of consolidation. So far as individual rocks are concerned, we look to experiment rather than to observation to give precision and definiteness to our ideas regarding the nature of the changes which accompany solidification.

THE ORIGIN OF SPECIES.

The geologist, however, has to deal not only with igneous rocks as individuals, but as groups, to consider their mutual relations, their geographical distribution, and mode of origin. But to give anything like a full account of the growth of ideas on this subject would expand this address to an inordinate length, and would, moreover, be a work of supererogation, for the whole question has been admirably reviewed by Professor Iddings and Professor Lœwinson-Lessing.

The germs of all the theories which are now struggling for existence can be discovered in the writings of our predecessors. Scrope (1825) held the view that lavas were formed from previously crystallized rocks, such as granite, and maintained that in the process of eruption, or intumescence, as he termed it, a kind of differentiation might take place, giving rise to trachyte and basalt. Darwin (1844), in his important work on Volcanic Islands, also discussed the origin of petrographical species. He directed attention to two causes of differentiation which may ultimately prove to be of great importance—(1) the movement of crystals in a magma under the influence of gravity, and (2) the squeezing or leaching out of the more fusible constituents from a partially consolidated or partially fused mass. The first of these he illustrated by the well-known Pattinson process for desilverizing lead, and the second might be illustrated by another metallurgical process often known as liquation (but quite distinct from the process referred to by Durocher under the same name), by means of which silver is separated from blister copper. The copper is fused with a certain proportion of lead, and the bars are maintained at a temperature above the fusing point of the silver lead alloy and below that of copper. The silver lead alloy is thus leached out of the copper, which remains as a

solid porous mass. Such a separation might be effected in the case of a plutonic mass, if a partially solidified magma were subjected to pressure under conditions which admitted of the escape of the still liquid portions into the surrounding rocks. As a matter of fact, it has been so applied by Mr. Barrow, who thus explains the relation between pegmatites and certain oligoclase-biotite-gneisses in the southern Highlands of Scotland. The eurite veins in granite are generally supposed to owe their origin to a somewhat similar action, but in this case the separation is due to the leaching out of the still liquid eutectic into cracks in the nearly consolidated mass, and not to orogenetic movements. It is comparable, therefore, to the liquation process above mentioned.

Bunsen explained the varieties of igneous rock revealed by his analyses by assuming the independent existence of two magmas—the "normal pyroxenic" and "normal trachytic"—and supposing a process of intermixture to account for the intermediate varieties. Von Waltershausen thought that igneous magmas were arranged in a series of concentric shells, according to specific gravity. Durocher, in his celebrated essay on Comparative Petrology, maintained "that all igneous rocks, modern and ancient, were derived from two magmas which coexist below the solid crust of the globe, and occupy there each a definite position." His two magmas—basic and acid—do not differ materially from those of Bunsen, and his idea of their arrangement in the earth's crust is practically the same as that of Von Waltershausen. He compared the two magmas to baths of fused metals, which separate into distinct alloys on cooling. He does not give actual illustrations, but we may consider one, in order to give precision to the idea. A mixture of 43.64 per cent of bismuth and 56.36 per cent of zinc separates at a temperature between 700° and 800° C. into two alloys, which arrange themselves according to specific gravity. On cooling, the heavier is found to contain 84.82 per cent of bismuth and 15.18 per cent of zinc; the lighter 2.47 per cent of bismuth and 97.53 per cent of zinc. If silver be added to the mixture, there is also a separation into two alloys, so long as the amount of silver is less than about 40 per cent; when it exceeds this amount, there is no longer any separation.

Durocher speaks of eruptions which derive their supply from the primary magmas as belonging to the first order, and those which draw their material from more or less isolated magma basins as belonging to the second order. The latter furnish rocks which depart from the normal type, and this he explains, in part at least, by assuming a process of separation analogous to that by which the primary magmas were produced. Thus he says:

"It is therefore probable that phonolitic and trachytic porphyry are only the two opposite products of a liquation which took place in the midst of the fluid mass; they are, as it were, the two inverse alloys into which we so often see a metallic bath divide itself."

The type of magmatic differentiation conceived by Durocher may be illustrated by a very simple experiment. Place some phenol and water in a Florence flask; two immiscible conjugate solutions will be formed—a solution of water in phenol at the bottom and a solution of phenol in water at the top. Now heat the mixture to 69° C., and a perfectly homogeneous solution will be produced. On cooling, this will again break up into two. Clouds are first formed in the cooler portions of the liquid, and after the coalescence of the minute drops, gravity is able to effect a perfect separation of the two solutions.

Do silicate solutions behave in the same way? Bäckström has recently argued that they do; but until the fact has been definitely established by experiment, there will always remain a certain element of doubt. The sharp separation of basalt and granophyre, which is so striking a feature of the Brito-Icelandic province, suggests that the two magmas represented by these rocks may separate in the manner just described. But the great viscosity of fused granophyre at atmospheric pressure and easily accessible temperatures would probably prevent the attainment of any decisive result.

Clarence King maintained that local lakes of fusion were formed by relief of pressure, and that differentiation took place partly by liquation in Durocher's sense, and partly by the rise or fall of crystals.

The physico-chemical speculations, which played so important a part in the science of rocks during the middle of the century, were neglected for a time, in consequence of the opening up of a new field of observation by the introduction of the microscope; but of late years we have returned to these speculations with renewed vigor, and with a wealth of facts at our disposal which the earlier theorists would have envied.

The mineralogical composition and microscopic structure of all kinds of igneous rocks have been determined, reliable chemical analyses have been made, and the problem of the origin of petrographical species has resolved itself into the question of the evolution of the magmas. Especially noteworthy is the stimulus given to the chemical side of petrology by the magnificent work of the United States Geological Survey. We have now some four or five new and original classifications of igneous rocks largely based on the analyses of Clarke, Hillebrand, and their assistants, and the cry is, "Still they come!" But the authors of these analyses have hitherto refrained—perhaps wisely—from attempting any general classification of rocks from a chemical point of view. The number of constituents is so large that there is no reason, so far as I can see, why every petrographer should not have his own classification and his own method of graphical representation.

The idea that petrographical species have originated by differentiation from homogeneous magmas, and possibly in the first instance from some one primordial magma, has been greatly developed during the last decade of the century, especially by American and Norwegian

petrographers. Thus Professor Iddings, in the introduction to his important memoir on the Origin of Igneous Rocks, says:

"The object of the present paper is to give the writer's reasons for concluding that all of the volcanic and other igneous rocks of any region are so intimately connected together by mineralogical and chemical relations that they must have originated from some single magma whose composition may be different in different regions; and, further, that it is the chemical differentiation of this primary magma which has given rise to the various kinds of igneous rocks."

The fact that the diverse igneous rocks of certain districts are often bound together by common mineralogical and chemical characters which distinguish them from the corresponding rocks of certain other districts was clearly recognized by Professor Judd in his well-known paper on the Volcano of Chemnitz, and subsequently crystallized by him in the happy expression petrographical province, as applied to any district in which the igneous rocks have certain common characteristics. The idea has been still further extended and elaborated by Professor Iddings, who sees in the common characteristics the indications of a kind of blood relationship or consanguinity, which can only be explained on the assumption that the different species of one and the same province have originated by differentiation from a single homogeneous magma.

Professor Brögger, in his remarkable series of studies on the rocks of the Christiania district, has still further generalized this idea, and much of his work is directed toward the evolution of a genealogical tree, in which the twigs shall correspond to the final products of differentiation, the larger branches to some of the plutonic masses, and the trunk to the primordial homogeneous magma. The idea is a fascinating one: se non è vero, è ben trovato. But it must be admitted that we know very little about the causes of the assumed differentiation. These are supposed to be of two types: (1) those which affect the liquid magmas, and (2) those connected with the separation of the minerals. Magmatic differentiation is generally regarded as the most important, but it is the type of which we know least. Soret's principle, to which I have appealed, will, I fear, help us very little, though it is undoubtedly a vera causa. Mr. Harker has clearly shown that, as applied to a mass like the Carrock-Fell gabbro, it breaks down hopelessly when subjected to a quantitative test. The principle of Gouy and Chaperon is even more unsatisfactory. Durocher's liquation theory is, perhaps, more promising, but until it has been proved by actual experiment that there is a real analogy between baths of fused metals and silicate-magmas, it can not be said to rest upon an assured basis. Faraday's researches on lead glass certainly suggest that gravity may act differentially on the constituents of silicate-magmas, independently of the principle of Gouy and Chaperon. Thus he found that glass taken from the top of pots not more than 6 inches

deep might have a density of 3.28 while that from the bottom might have a density of 3.85; but there is some doubt as to whether the constituents were ever uniformly mixed in the molten state, and if not, whether sufficient time was allowed for diffusion to establish homogeneity. It is certain, however, that they were uniformly mixed in the solid state, and the experiments are therefore of great interest; for, if they do not prove differentiation in a molten mass they prove that a uniform solid mass may become differentiated as it liquefies by a kind of liquation process analogous to that which takes place in the extraction of silver from copper.

Professor Iddings has carefully considered the chemical compositions of groups of rocks belonging to several different petrographical provinces from the point of view of the differentiation hypothesis, and has arrived at the conclusion that "the simple oxide molecules shift about independently of one another to a great extent." If this conclusion be correct, it is clear that the phenomena can not be explained by the hypothesis of a differentiation solely connected with the formation of known minerals. But this view does not appear to be accepted by Professor Brögger, who believes "that the process of differentiation must be referred to magmatic diffusion of definite chemical compounds to and from the cooling surface; further, that these diffusion phenomena in all probability stand in direct relation to the order of crystallization of minerals in the corresponding magma, and, lastly, that the order of crystallization, the nature of the differentiation, and the sequence of eruptions are all closely related phenomena."

Differentiation dependent upon crystallization rests on a somewhat firmer basis, and it was this kind of differentiation that first attracted my attention. Mr. Clough, while mapping the Cheviot district, proved that the widespread series of andesitic lavas is cut by a number of quartz-felsite dikes. Why did quartz-felsite succeed andesite in the Cheviot district? This was the question which kept continually recurring to me during my examination of the rocks of the district. Now, a microscopic examination of the andesites proved that the phenocrysts taken together must have the composition of a basic rock, for they were composed of labradorite, augite, and hypersthene, and therefore the glassy base present in some of the andesites must be allied to quartz-felsite in composition. The sequence established by Mr. Clough could therefore be explained by the assumption that the quartz-felsite magma represented the mother liquor of the andesitic magma, after the phenocrysts had separated out. Thus, if crystallization had progressed in the plutonic mass to the stage represented by the phenocrysts of the lava, or a little further, and the mother liquor had then been squeezed out as one squeezes water out of a sponge, or separated in any other way, and forced upward into cracks in the overlying series of andesitic lava flows, the question above referred to could be

satisfactorily answered. I was fortunately able to test the theory quantitatively, for Mr. Waller had already analyzed one of the quartz-felsites, and Dr. Petersen had published analyses of the glassy base of one of the andesites and of the devitrified base of another. On comparing the mean of the two analyses of the base with the analysis of the quartz-felsite, it was found that of the eight constituents six differed by less than 0.4 per cent, silica differed by 2.2, and soda by 1.46.[a]

	I.	II.	III.	IV.	Diff.
SiO_2	66.25	65.16	65.70	67.9	+2.20
Al_2O_3	13.59	17.49	15.54	15.7	+0.16
Fe_2O_3	3.11	3.01	3.06	3.0	−0.06
CaO	2.75	0.84	1.79	1.4	−0.39
MgO	0.28	2.34	1.31	1.5	+0.19
K_2O	4.95	5.54	5.24	5.6	+0.36
Na_2O	2.25	3.68	2.96	1.5	−1.46
Loss	5.89	1.76	3.82	3.7	−0.12
	99.07	99.82	99.42	100.3	

I=Glassy base of hypersthene-andesite from Fairhaugh, Usway Burn, Cheviots. (Ebert.)
II=Devitrified base of andesite, 2 miles up Allerhope Burn. (Wulf.)
III=Mean of the two analyses.
IV=Quartz-felsite from dike on the Coquet, one-half mile above Shillmore farm, Cheviots. (Waller.)

Differentiation dependent on crystallization is a fact which can not be denied; for the igneous magma, except when it cools as a glass, separates into distinct minerals which do not, as a rule, consolidate simultaneously. But the acceptance of this fact does not involve the acceptance of the differentiation theory of the origin of petrographical species, for, as M. Michel Lévy points out, the crystallization of a magma under ordinary circumstances does not commence until it has reached a pasty state. MM. Fouqué and Lévy observed no tendency to differentiation, of the kind required to produce petrographical species, in their celebrated synthetical experiments. The centers of crystallization were uniformly distributed throughout the masses, which were too viscous to allow of any appreciable movement of the first-formed minerals. Nevertheless, the facts observed by Darwin and others clearly prove that in large masses of lava, even at the surface of the earth, movement of crystals is possible in igneous magmas, and M. Michel Lévy himself admits that such movement may become an important factor under certain circumstances.

Mr. Harker has suggested another way in which crystallization may operate so as to produce variation in a mass of rock. He has shown that the Carrock-Fell gabbro varies in composition from the center to the sides, and that, as so frequently happens in eruptive masses, the latter are more basic than the former. He considers "that the differentiation took place by diffusion in a fluid magma, but not as a process distinct from and quite anterior to crystallization. It was, as I believe, effected in a quasi-saturated magma, concurrently with the crystalliza-

[a] As the figures were not placed side by side in the original paper (Geol. Mag., 1885, p. 106), I so place them now.

tion of the earlier-formed minerals; * * * the characteristic of all [such occurrences] is that the several constituents are concentrated in a definite order, which is identical with the order in which they crystallize out from the magma."

All theories which depend on diffusion or molecular flow have been criticized by Mr. Becker on the ground that the rate of diffusion is too slow to produce the results attributed to it in any reasonable time. He shows that, in the case of a column of water resting upon a layer of copper sulphate, the lapse of 1,000,000 years would be required to produce sensible discoloration at a height of 350 meters, or semisaturation at a height of 84 meters; and he considers that the molecular flow of any compound in a silicate magma would probably be at least fifty times less rapid, so that a mass of lava 1 cubic kilometer in volume "would not have had time to segregate into distinctly different rocks by molecular flow if it had been kept melted since the close of the Archæan period." I am by no means averse to making heavy drafts on the bank of time for geological purposes, but unless some effective answer to Mr. Becker's arguments can be found I think that we shall have to give up unaided molecular flow as an important factor in the origin of petrographical species.

Mr. Becker has not, however, simply confined himself to destructive criticism. He has proposed a theory of differentiation dependent on "fractional crystallization." During the cooling of a mass of molten matter in a dike or laccolite, convection currents will be established. These will act as stirrers, and, aided by diffusion, will tend rapidly to restore homogeneity in the liquid mass after it has been destroyed by the deposition of the first-formed crystals on the walls of the cooling surfaces. He compares a laccolite, in which the marginal parts are different from the center, to a barrel of cider which has been frozen from the outside. During the earlier stages nearly pure ice is formed on the walls, while the alcohol is concentrated in the central portion; from this a liquor, gradually increasing in strength, may be drawn off as consolidation progresses. Here we see a further development of the idea originated by Darwin.

All forms of the differentiation theory take as their starting point a homogeneous magma, and then proceed to derive from it the different varieties of igneous rocks as we now see them by magmatic or some other form of differentiation. Are we justified in taking this view? As applied to certain districts, and especially to the Christiania district which Professor Brögger has done so much to elucidate, it has proved of great value. But if we look at the general question, there are many facts which should give us pause. The earth's crust is certainly heterogeneous, and if magmas are, in any case, formed by the refusion of solid rocks, it is probable, as Mr. Becker has pointed out, that such magmas would be heterogeneous at the start. Even the

refusion of homogeneous rocks may give rise to a heterogeneous magma, comparable to that produced by Faraday in his experiments on glass. The cause of some of the variations in igneous rocks is therefore probably to be sought for in actions which antedate the formation of the magmas. But even homogeneous magmas may become modified by the absorption or assimilation of the rocks through which they pass. This point has been clearly established and especially emphasized by M. Michel Lévy, Professor Barrois, and Professor Lacroix in France, and by Dr. Johnston Lavis, Professor Sollas, Professor Cole, and Mr. Harker in this country.

That it is a vera causa is admitted on all hands, but differences of opinion exist as to the extent to which it should be applied in explaining the origin of petrographical species.

If we study igneous rocks which have appeared at the surface as lavas, or have been intruded at moderate depths as dykes, sills, laccolites, or bosses, the evidence of absorption is, in my judgment, so slight as to be practically negligible; but if we pass from such regions to others in which plutonic rocks are found in relation with crystalline schists and study "les appareils granitiques à racines profondes" of M. Michel Lévy, the case is different. It may be that the final solution of the problem of the origin of igneous magmas will be found in these regions; but here we touch a question which belongs to the future rather than to the past, and lies, therefore, beyond the scope of this address. So far as I am concerned, I will confess that my ideas are not fixed. At present I am not disposed to attach much importance to theories involving differentiation in situ by unaided molecular flow in dikes and laccolites; but rather to attribute such variation as does occur to successive eruptions, or to a continuous change in the nature of the material during the process of intrusion. The great difficulty in applying any theory that involves differentiation in situ to such cases arises from the slight effect of the igneous magmas on the containing walls—a fact which negatives the idea that the material arrived at the place where we now find it in a condition of superfusion, or that it remained fluid long enough to enable any considerable diffusion to take place.

Our ideas as to the origin of igneous rocks are still "en pleine évolution." Conditions are rapidly changing in consequence of discoveries in geology and physical chemistry. Rival theories are struggling for existence, and although it is safe to predict that some will become extinct, that others will be modified, and that natural selection will finally bring about the survival of the fittest, it is impossible to determine at present the relative importance of those which claim our attention.

The origin of petrographical species, so far as the igneous rocks are concerned, is a problem the final solution of which has been handed on by the nineteenth century to its successor.

PRELIMINARY REPORT ON THE RECENT ERUPTION OF THE SOUFRIÈRE IN ST. VINCENT, AND OF A VISIT TO MONT PELÉE, IN MARTINIQUE.[a]

By Tempest Anderson, M. D., B. Sc., F. G. S., and John S. Flett, M. A., D. Sc., F. G. S.[b]

[Dr. Tempest Anderson and Dr. John S. Flett, who received a commission from the Royal Society to investigate the recent volcanic eruptions in the West Indies, more especially in St. Vincent, submit the following preliminary report:]

We arrived at Barbados on June 8 (having left London on May 28), and thence proceeded to St. Vincent, where nearly four weeks were spent, mostly at Chateaubelair and Georgetown, in the vicinity of the Soufrière. On June 29 Dr. Tempest Anderson went to Grenada to examine the lagoon at St. George's, returning some days later, Dr. Flett remaining at St. Vincent to complete his investigations.

On July 6 we arrived at Martinique, and on the 12th left that island for Dominica, where we remained until July 17, when we returned to Barbados. In all six weeks were spent in the West Indies.

In the Windward Islands, in the month of July—the middle of the rainy season—the work of a geological expedition is necessarily attended with many difficulties, but these were greatly mitigated by the kindness rendered by all with whom we came in contact. To Sir Robert Llewelyn, K. C. M. G., the governor of the Windward Islands, and to the administrators of St. Vincent, St. Lucia, and Dominica, and other officials connected with the colonial office, we are especially indebted for information, advice, and assistance. Dr. Morris, C. M. G., of the imperial department of agriculture for the West Indies, and the members of this department in the various islands received us with the greatest kindness and gave us invaluable help throughout. The many planters and overseers of estates, medical men, and merchants to whom we made application for information or for assistance received us with that courtesy and hospitality which are characteristic of the colony, and

[a] Reprinted, by permission, after revision by the authors, from Proceedings of the Royal Society, London, Vol. LXX, No. 465, August 22, 1902.

[b] Communicated by the secretaries of the Royal Society. Received August 11, 1902.

did everything in their power to forward our work in every way. In Martinique the governor of the island gave us every facility for conducting our scientific investigations. In this brief preliminary report it is impossible for us to mention by name even a small proportion of those who, often at considerable inconvenience to themselves, lightened our labors by their kind provision and forethought. In every place we visited we found friends who were willing to direct, assist, and accompany us; and without their help it would often have been impossible for us to make satisfactory arrangements or to accomplish our work. In this way what might have been a very arduous undertaking was greatly lightened, and we wish to place on record our deep indebtedness to our many kind friends in the Windward and Leeward islands.

The island of St. Vincent is of oval form, 18 miles by 11 miles, the longer diameter being nearly north and south. A mountain chain stretches along the main axis of the island and reaches to a height of 2,000 to 4,000 feet, the highest point being just over 4,000. It is entirely composed of volcanic materials, the beds of lava and tuff dipping away in all directions from the central mass toward the sea. In the southern part of the island volcanic action has long been extinct or dormant, but at the northern end stands the still active Soufrière, a striking volcanic cone 4,048 feet in height, with a crater nearly circular in form and about 1 mile in diameter. Along the leeward side of the island very fine sections are exposed, and these show it to consist of volcanic rocks, of which by far the commonest is a coarse andesitic agglomerate or tuff, though there are many lava streams which may be traced as vertical cliffs along the valley sides, alternating with the gentler slopes due to the thick beds of ash. The scenery is bold and picturesque, the heavy tropical rains acting on steep slopes having effected rapid and intense erosion. As a consequence, deep valleys radiate out from the central ridge, separated by high, narrow spurs running down to the sea. On the windward side, below the level of 700 feet above the sea, there are considerable stretches of flat or gently sloping ground on which stand many of the most important arrowroot and sugar estates. The first glance at these lower grounds suffices to show that they are very distinct in configuration from the highly eroded and deeply sculptured uplands, and further investigation reveals the presence of more or less well-marked beaches or terraces—a system of old sea beaches or rock platforms partly obliterated by subaerial erosions and in some places covered with débris. On both sides the submarine slopes are steep, but most so on the leeward coast, as on the east or windward side there is a considerable expanse of shallow water in which a submerged terrace at a depth of 150 feet can be traced by means of soundings, as indicated on the charts. There are no raised coral beaches here, as in some of the other islands, and the latest movements of the land have probably been in a downward direction.

The Soufrière Mountain forms the northern extremity of the island, and its general form at once suggests a comparison with Vesuvius. It is a simple cone without lateral or parasitic craters. The one at its summit is surrounded on the north side by the remains of a gigantic crater ring, which has the same relation to the present crater as Somma has to Vesuvius. On the northeast lip of the main crater there is a smaller one known as the New Crater, as it is believed to have originated in the eruption of 1812. It is only one-third of a mile in diameter. It is doubtful whether the New Crater was active during the late eruption, and there can be no doubt that it was from the principal or "Old Crater," that the materials mostly were emitted. Deep valleys, often with precipitous sides, have been cut in the slopes of the mountain, especially on its southern side, and it is in these—and particularly in the Wallibu, Rozeau, and Rabaca Dry River—that the greater part of the ejecta of the recent eruption have collected.

The eruption of May, 1902, though sudden in its outburst and disastrous in its effects, was far from unexpected. In the north of St. Vincent there were two settlements of the aboriginal Caribs, and these had been so startled by the frequent violent earthquakes, that in February of last year they were considering the advisability of deserting the district. But the first signs of actual volcanic activity were on Tuesday, May 6. The inhabitants of the leeward side were fortunate in having a clear view of the crater, and, warned by the outbursts of steam, they fled to Chateaubelair and other places along the coast line to the south, so that few lives were lost in this quarter. But, on the windward side, the summit of the mountain, as is frequently the case, was wrapped in cloud. Here, at the base of the mountain, there is an extensive stretch of flat land, known as the Carib country, on which were situated some of the largest and richest estates in the island, with a dense population mostly black or colored. So little alarm was felt here that even on the morning of Wednesday, May 7, when the leeward side was practically deserted, sugar making was in progress on several estates, and all the operations of tropical agriculture were being conducted as usual. From Kingstown telephonic messages were sent to Georgetown, which is not far from the base of the hill, stating that the Soufrière was in eruption, but they appear to have occasioned little anxiety. And when, about midday on Wednesday, the danger was too obvious to be overlooked, the Rabaca Dry River, and some of the streams on the windward side, usually dry except after rains, were running boiling hot, and could not be crossed. Many fugitives in this way found their escape cut off. It was here that the loss of life was greatest, which, though many escaped, is estimated to have amounted to 2,000, including about a dozen white men—the overseers of the plantations. The exact number will never be known, as many were entombed in the ashes where they fell.

About midday on Tuesday the first signs of the eruption were observed by those dwelling on the southwestern side of the mountain. At 2.40 that afternoon there was a considerable explosion, and a large cloud of steam ascended into the air. By 5 o'clock a red glare was visible in the steam cloud on the summit. Activity continued during the evening, and at midnight there was a great outburst and red flames were noticed on the lip of the crater. Next morning from Chateaubelair a splendid view could be obtained of gigantic mushroom-shaped clouds rising to a great height in the air—estimated at 30,000 feet—and drifting away before the northeast trade wind. As the day advanced the eruption increased in violence; by 10.30 a. m. enormous clouds of vapor were being emitted with loud noises, accompanied by much lightning. It is remarkable that at that time the inhabitants of the windward side were still in doubt about the reality of the eruption, since they mistook the dark cloud covering the mountain for a thunder cloud. The mountain was now in a state of continuous activity, and from Chateaubelair it could be seen that the materials were mostly discharged from the old or principal crater. Vast clouds of steam, showers of dark matter (probably mud), and of stones, could be seen projected from it, partly on the leeward, but mostly on the windward side. At midday the slopes of the mountain were still green and the rich mantle of tropical vegetation had not yet been destroyed. A thin layer of fine ash had fallen over the lower ground, only sufficient to give the leaves a grayish color. The enormous columns of vapor continued to ascend from the crater, with frequent violent outbursts, projecting showers of stones and mud.

About this time it was noticed that steam was rising from some of the valleys on the south side of the hill, and this increased till at 12.50 the whole mountain was suddenly enveloped in a dense cloud of vapor. Just before this the rivers Wallibu and Rabaca had been seen rushing down in raging floods of boiling water. It is most probable that these phenomena were due to the escape of the crater lake, which was driven over the lower or south lip of the crater between 12 o'clock and 1 o'clock on the Wednesday afternoon, and poured down the valleys to the sea. So far as we know there were no mud lavas, in the ordinary sense, flowing down these valleys, but only a tremendous rush of boiling water, which left no traces which we could recognize when we visited the district.

By 1 o'clock the roaring of the volcano was tremendous. Showers of stones were being projected both to windward and to leeward. The enormous columns of steam continued to ascend from the crater. The lightnings were terrific, and after the large outbursts which took place every few minutes volumes of vapor might be seen covering the whole area. Hitherto the eruption had been of a type with which geologists are familiar, and the destruction done was confined to the higher parts of the mountain in the close vicinity of the crater.

But about 2 o'clock—to quote the words of an eyewitness (Mr. T. M. McDonald, of Richmond Vale Estate)—"there was a rumbling and a large black outburst with showers of stones, all to windward, and enormously increased activity over the whole area. A terrific, huge reddish and purplish curtain advanced to and over Richmond Estate." This was the strange black cloud which, laden with hot dust, swept with terrific velocity down the mountain side, burying the country in hot sand, suffocating and burning all living creatures in its path, and devouring the rich vegetation of the hill with one burning blast.

On the leeward coast few were overtaken by the black cloud, as the inhabitants had fled and taken refuge in the villages south of Chateaubelair. Those who were caught were killed or badly burned. One boat was near Richmond at the time the blast swept down. They describe the heat as fearful. Hot sand rained into the boat and the sea around was hissing with its heat. The darkness was so complete that a man could not see his hand. They saved their lives by diving into the water; when they returned to the surface the air was suffocating, but they continued to dive again and again, and, when at their last gasp, they found that the air cleared and they could breathe again. This occupied only a few minutes—probably much less in reality than it appeared to them. One man was too exhausted to continue diving; he clung to the gunwale of the boat, and the tops of his ears were severely scorched.

It may be worth while to quote the descriptions of a few spectators who saw this cloud from a safe distance. Dr. Christian Branch, of Kingstown, writes:

"We saw a solid black wall of smoke falling into the sea about 2 or 3 miles from us. It looked like a promontory of solid land, but it rolled and tumbled and spread itself out until in a little time it extended quite 8 miles over the sea to the west. * * * Then began the most gorgeous display of lightning one could conceive. * * * It was still bright daylight, but the whole atmosphere quivered and thundered with wavy lines intersecting one another like trelliswork. We were encircled in a ring of fiery bayonets."

Another eyewitness (the Rev. Mr. Darrell, of Kingstown), who was in the same boat with Dr. Branch, describes it as follows:

"We were rapidly proceeding to our point of observation when we saw an immense cloud—dark, dense, and apparently thick with volcanic material—descending over our pathway, impeding our progress and warning us to proceed no farther. This gigantic bank of sulphurous vapor and smoke assumed at one time the shape of a gigantic promontory, then as a collection of twisting, revolving cloud whirls, turning with rapid velocity—now assuming the shape of gigantic cauliflowers, then efflorescing into beautiful flower shapes, some dark, some effulgent, some bronze, others pearly white, and all brilliantly illumined by electric flashes."

On the windward side of the island an uninterrupted view of the progress of the eruption could not be obtained, owing to the veil of cloud which obscured the summit. By midday on Wednesday even the most skeptical were convinced that the Soufrière was in eruption, and that the noises heard continuously were not due to a thunderstorm. Before midday there had been very heavy rain showers, and it was noticed that the raindrops carried down fine particles of ash. Work ceased on the plantations, and those laborers who still remained endeavored to escape to Georgetown or shut themselves up in their houses. By 2 o'clock fine ashes, with occasional larger stones, were falling steadily, but, as yet, little damage had been done, and no one had been injured. Then came the climax of the eruption, and those who were in the open air saw a dense black cloud rolling with terrific velocity down the mountain. They took refuge in their houses and in the plantation works, where they crowded together in such numbers that in one small room 87 were killed. The cloud was seen to roll down upon the sea, and was described to us as flashing with lightning, especially when it touched the water. All state that it was intensely hot, smelt strongly of sulphur, and was suffocating. They felt as if something was compressing their throats, and as if there was no air to breathe. There was no fire in the ordinary sense of the word, only the air was itself intensely hot and was charged with hot dust. The suffocating cloud only lasted a few minutes. Those who survived this ordeal mostly escaped, though many died within a few hours from shock, or from the severity of their injuries. In some cases a few survived, entirely or almost entirely uninjured, in a room in which many others died. Most of those who escaped had shut themselves up in the rum cellars or in substantially built houses, and had firmly closed all doors and windows. By the time the hot blast had reached the coast the sand it contained was no longer incandescent, and though still at a very high temperature it did not set fire to wood or burn the clothes of those exposed to it. The burns on the survivors were chiefly on the outer aspect of the arms and legs, and on the faces, and confined to parts not protected by their clothes.

Complete darkness now covered the whole north end of St. Vincent—a darkness more intense than any that the inhabitants had ever before experienced. The fugitives had to creep along the roads or feel their way along the roadsides. The roaring of the mountain was terrible—a long, drawn out, continuous sound resembling the roar of a gigantic animal in great pain. Fine ash and sand rained down over the whole country, with occasional showers of large stones. Some of these were so hot as to set fire to the "trash" roofs of huts in the south end of Georgetown, at a distance of 7 miles from the crater. In Kingstown, 12 miles from the Soufrière, the ash was at first moist, but afterwards dry. It had a strong sulphurous smell, and pattered

on the roofs like a heavy shower of tropical rain. Around the volcano the earth shook and trembled continuously, and the motion was described to us as undulating rather than resembling the sharp shock of an earthquake. Only in one or two cases were the walls of houses injured. What was taking place on the summit of the mountain no one can tell, but all who passed that night in the vicinity of the Soufrière agree that there was one black suffocating cloud, and only one. In all probability the eruption had reassumed the ordinary phase, and the showers of ash and stones were produced by violent upward explosions of steam. By half past 5 o'clock the ash was falling in Barbados, 100 miles to the eastward, whither it had been carried by the upper currents of air in a direction opposite to that of the trade winds. In St. Vincent the darkness lessened slightly before nightfall, but the rain of dust and the noises lasted till early in the ensuing morning,

When day broke it was seen that in St. Vincent, and even in Barbados, everything was covered with fine gray ash, resembling a fall of snow. The dust had penetrated into the interior of the houses, where it lay in a thin film on walls and furniture. In Kingstown there were stones as large as a hen's egg; in Georgetown and Chateaubelair some had fallen as much as 1 foot in diameter. Little damage, however, appears to have been done to growing crops, except in the north end of the island. In fact, many believe that the sulphurous ash had insecticidal properties, and benefited the vegetation. From Chateaubelair it could be seen that the volcano was still emitting puffs of slaty-colored steam, and showers of fine dust were falling on the leeward side of the mountain. For several days these discharges of vapors continued, but a new phenomenon now attracted more attention. The ravines which furrow the south side of the mountain were found to be discharging clouds of vapor, and this gave rise to reports of fissures having opened on the flanks of the Soufrière, of subsidiary eruptions arising from these fissures, and of streams of lava flowing down the valleys. As a matter of fact, they were really due to the action of water flowing through the hot sand, which in some places had almost obliterated the old stream courses, as will be explained more fully later on. By the 15th the volcanic activity had apparently subsided, and the mountain remained clear and unclouded. The explosions of steam in the valleys continued, and are probably still going on.

The state of quiescence continued till Sunday, May 18. Confidence was being restored, and the inhabitants of those districts near the mountain which had not suffered severely were returning to their homes. On the windward side the work of burying the bodies had been completed and things were resuming their normal course. But about 8 o'clock that evening an ominous sound was heard from the crater. Its nature was at once recognized and struck the black popu-

lation with terror. The noises were as loud as those of the first eruption, and the lightning was very vivid. On the leeward side complete darkness prevailed, and ashes and sand fell freely for some hours. In Georgetown the fall of ashes was quite inconsiderable, not exceeding a thin film on the roofs of the houses. Gradually the noises lessened, the darkness lifted, and the moon appeared again. No lives were lost and practically no damage was done, but exactly what happened on those parts of the mountain nearest the crater it is, under the circumstances, impossible to say. This second eruption was the last which proceeded from the main crater. Clouds of steam were sometimes seen gently rising for some days later, but nothing of the nature of a volcanic outburst has since taken place.

We arrived at Kingstown on Tuesday, June 10, and proceeded at once to Chateaubelair, where Mr. James E. Richards, of Kingstown, kindly placed a house at our disposal. The geological products of this eruption proved to be of very simple character. The Soufrière and the surrounding country were covered with a layer of ashes mostly in the form of fine, dark-colored sand, but mixed with spongy bombs of various sizes, and many ejected blocks composed of fragments of the old rocks of the hill. Lapilli and scoria are there in plenty, as is obvious where the heavy rains have washed away the finer material, but the greater part of the ejecta consists of fine sand, which when dry and hot is yellowish gray in color, but when wet becomes almost black. This sand, as has already been noted by many observers, contains plagioclase feldspar, hypersthene, augite, magnetite, and fragments of glass, and represents a fairly well crystalized hypersthene-andesite magna which has been blown to powder by the expansion of occluded steam.

The coarser material is mostly a slaggy andesite with crystals of plagioclase and pyroxene. There is little pumice, though we obtained a few fragments which floated on water and contained but few crystals visible to the naked eye. The larger bombs are often black, highly lustrous, and glassy when broken across. Some were seen at Wallibu (4 miles from the crater) 3 feet in diameter. The ejected blocks consist of weathered andesites and andesitic tuffs such as can be seen in the walls of the crater. They are very numerous, and some are over 5 feet across. In addition to these, fine-grained, dark-green banded rocks occur, which appear to be baked and indurated sediments, probably the mud from the bottom of the crater lake or the finer beds intercalated in the older volcanic series. Another type of ejected block which is very common in some parts of the hill is a coarse-grained aggregate of feldspar, hornblende (brown under the microscope), and perhaps olivine. It is not vesicular and contains little or no glass, being apparently holocrystalline. These rocks are very friable, and the crystals are loosely aggregated together. They seemed

to us to be comparable to the sanidinites of the Eifel and many other modern volcanic districts. They are certainly quite unlike true plutonic diorites, both in their structure and in the character of their minerals.

It may be noted that none of these rocks are characteristic of this eruption, but all can be found among the older materials of the hill. The hardened, baked sediments were well known to the Caribs, who have long used them for the manufacture of their finer stone implements. The feldspar-hornblende blocks were found by us among the older rocks, and in some places even as rounded masses enveloped in the old lavas. Some of the fresher bombs in the river beds and on the seashore can hardly be distinguished from those which were the product of this eruption, though undoubtedly of much older date.

At Kingstown, as in Barbados, the deposit of volcanic dust and sand was so slight that, owing to the heavy tropical rains and the rapid growth of tropical vegetation, it readily disappeared, and when we arrived it was necessary to make careful search to find traces of it. In St. Vincent, to the south of Chateaubelair, on the leeward side, and from 2 miles south of Georgetown, on the windward side, the country had very much its normal appearance. To the north of these points, however, a sheet of volcanic ejecta covered the ground. Where it was thin it was rapidly disappearing. Every shower washed much of the finer matter into the streams, which were flowing full of sand and lapilli to the sea. In the fields the arrowroot was pushing up through the layer of ash and covering it with a mantle of green leaves. Around Georgetown the deposit is from 1 to 3 feet deep, and some of the blocks are a foot in diameter. On some of the sugar-cane fields in the Carib country the ash lies 4 feet deep, while on the higher slopes of the hill it is from 5 feet to over 12 feet (where it has gathered in the hollows). On the leeward side the ash is very deep in the valleys of the Wallibu and Rozeau Dry rivers, but north of Larikai it is much thinner—not above a foot or two. The north side of the mountain has, for reasons to be subsequently discussed, received comparatively little of the deposit, and at Point Espagnol, Owia, Fancy, and Quashie Point, along the north shore, the cliffs and the country for some short distance behind them are perfectly green and flourishing.

On the south side of the Soufrière a deep and broad valley has been eroded in the soft volcanic ash and agglomerate of which this part of the hill consists. It runs almost across the island, between the Morne Garu Mountain and the Soufrière, and it is this valley which has received the greater part of the ejecta of this eruption. The streams which flow into it—the Wallibu River on the west and the Rabaca Dry River on the east—have had their courses filled with fine, hot sand mixed with coarse bombs and ejected blocks. We were told that on

the west side the ravine of the Rabaca Dry River had been about 200 feet deep. It is now almost entirely filled up, and the river is slowly cutting its way through the hot sand which occupies it. The same thing is happening in the Wallibu Valley, but here erosion is more advanced, and cliffs of gray, hot ash, some 80 feet high, overlook the stream at a point about a mile above its mouth. On the flatter ground between the river gorges which trench these broad valley bottoms the deposit is very much thinner, perhaps 3 to 5 feet on the windward side, but often 12 feet, and sometimes 30 or 40 feet on the leeward side.

The distribution and thickness of the recent ashes is not at all such as would have been expected had these materials merely rained down from above. Wherever there is a hollow it has been filled up, however deep. For some days after the eruption the stream valleys were level with their banks. On the flat ground the deposit is much thinner, and on the ridges and spurs which stand up prominently there was comparatively little accumulation. To the mind of a geologist examining these valleys one comparison was irresistibly suggested—they resembled nothing so much as a rugged country covered with blown snow. The ash had drifted into and filled up the depressions, while comparatively little had rested on the ridges between. It is conceivable that mud lavas flowed down at an early period in the eruption, and occupied the lower parts of the gorges; but we saw no evidence of this, and as wherever the deeper layers of the ash are exposed they are still burning hot, it is obvious that they could never have reached their present position in the condition of a mud lava. When we saw this country its surface had been deeply scored by the rains, but those who visited it shortly after the first eruption described it as having a smooth, gently rolling surface like that of blown sand. This is well shown in photographs taken by Mr. Wilson, of Kingstown, on May 14. The conclusion was forced upon our minds that immense quantities of hot sand had rushed down the hill into these valleys in an avalanche which carried with it a terrific blast and piled the ashes deep in the sheltered ravines, at the same time sweeping everything off the exposed ridges which lay between. The rain of volcanic material, which lasted for hours after the hot blast had passed, then covered the surface of the country with a final sheeting of fine dust and scoria.

When we ascended the Soufrière, the evidence of the passage of a hot blast laden with sand was overwhelmingly clear. The various stages of its action, and its varying intensity at different spots, are most easily observed on the windward side, where the country is more flat and open and there are fewer ravines and spurs to modify the course of its operations than in the Wallibu Valley.

The track to the summit passes across the Rabaca Dry Valley near the shore, then turns upward through the sugar-cane fields of Rabaca and Lot 14. These were covered with 3 or 4 feet of sand and scoria.

the trees all bare, their leaves stripped by the falling cinders; but few branches were broken, and no trees had been uprooted or cast down. The woodwork of the houses was unburnt, though the roofs of some of the verandas and of the laborers' huts had collapsed from the weight of ashes that had fallen on them. Many people were killed on these estates. The survivors described to us how the dark cloud had rolled down from the mountain, and how hot and suffocating the air had been when it enveloped them. But it was evident that the velocity of the blast was not above that of an ordinary gale, and the dust it carried, though hot, was not incandescent.

At Lot 14 it was seen that many trees had their limbs twisted off and broken, and some of the negroes' houses had taken fire (probably mostly from hot falling bombs). The blast was more violent here, but not hot enough to set fire to the woodwork or char the green wood of the standing timber.

On the flat ground above the plantation buildings (at an elevation of about 1,000 feet) a further stage of devastation was encountered. The fields were here swept bare, the trees broken down, though not as a rule uprooted, and their smaller branches swept away; a deep layer of black sand covered the crops of sugar cane. The blast was here a violent gale.

A little farther up the effects of the blast were remarkable. Enormous trees had been uprooted and cast down. Their leaves and finer branches, of course, had disappeared. In every case the fallen trunks pointed directly away from the crater. Even the great cotton trees, 10 feet or more in diameter, were broken off or uprooted. The smaller trees had in a few cases been swept away like straws. The larger were merely cast down, and lay side by side, their tops directed down the valley, their roots toward the summit of the mountain. Most were charred, some deeply, but, as the wood was green, only the smaller branches had been consumed. The effect was like that produced by a violent hurricane, only more complete, for many of these trees had withstood the hurricane which ruined St. Vincent in 1898. At the lower limit of this region some curious effects of the hot sand blast could be seen. Where any branches or trunks were still standing they invariably showed themselves to be burnt and eroded on one side—that next the crater—the wood having been charred and the charred material removed by the action of a hot sand blast. On the side away from the crater the original bark was still left unburnt, but dry and peeling off; that is, there had been no erosion on the sheltered or lee side of the stems. The wood was too green to take fire, but the sand had been sufficiently hot to char the surfaces which were exposed to it.

Farther up the hill—that is to say, above the 1,500 feet level—there was little left of the rich tropical vegetation which had covered it

from summit to base. Blackened remains of tree trunks were to be seen, overturned or broken off near the ground and buried in dark sand. The highest parts of the mountain are as bare and desolate a scene as could be imagined. The ash is 5 to 12 feet deep, and though full of large blocks and spongy bombs, is mostly so fine that when thoroughly wet it becomes a mud, very tenacious and slippery, in which one sinks to the knee. In it there is a good deal of burnt timber, utterly blackened and converted into charcoal. Everything has been mown down, and at the same time the intense heat has consumed all the smaller fragments and charred the larger. There is nothing to show what was the velocity of the blast when it left the crater. After a couple of miles it was that of a hurricane or tornado. The limits between the zone of uprooted trees and that of trees still standing, but broken and much damaged, is surprisingly sharp. At 4 miles from the crater the blast was traveling at 20 to 40 miles an hour, and rapidly slowing down. This agrees with the evidence of an eyewitness who saw it when it reached the sea near Chateaubelair. It came over the water with a wave before it, but it did not overturn the small boats which lay in its course.

Another peculiar feature of this blast is the manner in which its course was modified by irregularities in the configuration of the ground over which it passed. To the north of the crater stands the encircling crater wall already referred to as the Somma. There can be no doubt that a black cloud descended over this side of the mountain, though here the devastation is comparatively slight, and it is inferred that the high intervening ridge overlooking the crater served as a rampart and helped to protect the country behind it from the effects of the blast. The southern lip of the crater, on the other hand, is the lower, and the avalanche of hot sand seems to have poured over this lip almost like a fluid. Down the deep open valley between the Soufrière and the Morne Garu Mountain it rushed, ever following the steepest descent. It clung to the valley bottoms and coursed along them in a manner which somewhat recalls a raging torrent in a river. The streams in these valleys, after descending the first part of the hill, turn sharply at a right angle toward the coast, deflected by the opposing mass of the Morne Garu. The hot blast mostly followed these valleys, and in them it piled up enormous deposits of sand, but part of it swept up the shoulders of Morne Garu and tore up the heavy timber which was growing there. The direction in which the fallen trunks point shows that the blast was split into two parts—one taking the east and one the west side of the mountain—rushing upward obliquely from below. The mountain protected the country behind, and the line of demarcation between the burnt and the green forest almost corresponds with the dividing ridge. The south side is green; the north side toward the Soufrière is devastated and burnt.

The effect of even comparatively small ridges in deflecting the blast and protecting the country behind them is still more noticeable near Chateaubelair. Between the rivers Wallibu and Richmond there is a high dividing ridge. The northern valley (the Wallibu) is filled with ash and utterly burnt up, that to the south (Richmond Valley) is in large part green. One side of the dividing ridge is blasted; on the other the arrowroot is again putting out its green leaves. Another ridge separates Richmond Valley from Chateaubelair. This ridge has been in many places scorched, but the country behind it has been perfectly protected, and, though covered with the rain of ash, has resumed its normal appearance. There can be little doubt these ridges served to direct the path and intercept the violence of the hot blast.

For some days after the eruption no rain fell, and the first to visit the district were able to observe the effects of the eruption unmodified by the erosive action of running water. But on May 25 5¼ inches of rain fell. On the previous day the rainfall had been 2½ inches, and the rainy season now set in in earnest. The effect of these deluges acting on loose material lying on steep slopes was phenomenal, and by the time we reached the island the surface of the sheets of ash had been sculptured into innumerable furrows and runnels. They cut down through the incoherent sand to the layer of burnt vegetation on the old soil beneath, or even into this, forming new channels, which varied from a few inches to many feet in depth. To one fresh from a temperate climate and unaccustomed to the power of tropical rains the rapidity of denudation under these conditions was astounding. On the upper part of the Soufrière beautiful feather patterns of rain rills converging toward a central main axis everywhere characterized the surface. The knife edges between the valleys were the only parts retaining the original smooth surface, and they formed excellent paths, as the sand was firm, except near the summit of the hill.

On the windward side of St. Vincent so much material is being swept into the sea by the streams that the coast is covered with black sand, and near Overland Village it is possible to walk for a mile beneath the sea cliffs on a broad, sandy beach, where formerly the heavy surf of a weather shore beat against their base. In the arrowroot fields the original surface is often to a large extent uncovered, and on the upper slopes of the Soufrière there are many places where none of the new ash is left, but the bare surface of the old rocks is everywhere exposed to view. After a heavy tropical shower valleys which are usually dry may be filled with a thundering torrent several feet deep and 20 or 30 feet across. Under these circumstances it will easily be understood that already many of the streams have thoroughly cleaned out the ash from the upper parts of their channels where the gradient is steepest.

But when such a torrent reaches the lower valleys, which have been filled with thick masses of hot sand, a strange conflict between fire and

water can be witnessed. The river plows its way deeper and deeper, constantly sweeping the material into the sea. The valleys, at first almost obliterated, are now reassuming their old appearance. Terraces on their sides give evidence of former levels at which the streams flowed. There are five or six such terraces on the Wallibu. This river flows in gushes of hot steaming black mud, its intermittent flow being due to small landslides temporarily damming up its channel, only to be swept away as the pressure of the water increases. On the Rabaca Dry River there has been less erosion, and only after heavy rains does it reach the sea, as the water from the smaller showers is apparently evaporated in its passage through the banks of hot ashes. After rains both rivers can be seen steaming all along the lower parts of their courses.

When one of these streams comes down in force it undermines its banks by washing out the soft new ashes at their base. Then landslides take place, and a curious spectacle results. When the hot ash tumbles down into the water an immense cloud of steam rises in the air to heights of hundreds of feet. It expands in great globular masses exactly like the steam explosions from a crater, and as it drifts away before the wind fine dust rains from the cloud. We had the good fortune to witness a magnificent series of these explosions one day as we were descending from the summit of the Soufrière. It was in the valley of the Rozeau Dry River. After every landslip a column of muddy water rose to about 200 feet, carrying with it pieces of stone. Immense quantities of steam shot up to 700 or 800 feet in the air. It resembled an enormous geyser of black mud and steam. In the Wallibu River after every shower these steam explosions may be witnessed taking place on a large scale. After a few hours of dry weather they cease, though the river can still be seen to be steaming strongly as it flows along.

The structural modifications produced upon the hill by this eruption have been astonishingly slight. We saw no fissures, no parasitic craters or cones, and no lava streams. Even the craters at the summit retain essentially their old configuration. All the evidence points to the supposition that it was from the large or old crater that this eruption for the most part proceeded. But the smaller crater has not disappeared, nor has it been filled up. We did not see it, but we can rely on the evidence of several observers who knew it well before the eruption and have seen it since. The narrow ridge between it and the large crater still stands, though probably somewhat lower than before, and possibly is slipping down in landslides on both sides.

Like all the higher mountains of the Windward Islands, the Soufrière has usually its summit capped with cloud, especially during the rainy season, and this was the case on both the days on which we made the ascent. On the first occasion the mist lifted for a few minutes and

enabled us to obtain a glimpse of the bottom of the crater. Fortunately we had with us Mr. T. M. McDonald, of Richmond Vale, and Mr. Henry Powell, curator of the Botanic Gardens at Kingstown, who were both well acquainted with the mountain in previous years. The crater was formerly nine-tenths of a mile across and about 1,100 feet deep. Its inner slopes were steep and richly wooded. Its bottom was occupied by a lake which is said to have been over 500 feet deep. The northern wall is now a naked precipice of rock, perhaps 2,000 feet high, from the face of which rock slides are frequently tumbling into the abyss below with a loud noise. We did not get a clear view of it, but Professor Jaggar, of Harvard University, who ascended shortly before we did, was more fortunate, and obtained some photographs which show that it consists of layers of tuff alternating with beds of lava. What seems to be a thin irregular dyke forms a prominent riblike mass cutting across the bedding planes. The southern side slopes downward for several hundred feet at an angle of about 40°, and is covered with a thick layer of fine dark mud deeply grooved with rain channels. The lower part is a precipice of bare rock. The bottom of the crater is nearly flat or slightly cupped. When we saw it, it contained three small lakes of water, greenish and turbid, that in the southeast corner was throwing up jets of mud and steam with a hissing noise. It was in very much the same condition as when seen by the party which first ascended the mountain on May 31—that including Mr. T. M. McDonald and Professor Jaggar—and on a slightly later date by Lieutenant Robinson, R. E. Mr. McDonald thought that there was rather less steam and the lakes of water were somewhat larger than when he saw it previously. In his opinion and that of Mr. Powell the crater was only slightly larger than before the eruption, but considerably deeper. The estimates of the depth varied a good deal, but it seems, on the whole, to be generally agreed that it is about 1,600 feet.

Accurate measurements of the breadth or depth of the crater were, under the circumstances, impossible. As seen from Chateaubelair the outline of the lip of the crater has suffered many modifications, though none of these is of any great importance. It is agreed that the southern edge is now somewhat lower than it was before the eruption, and this is confirmed by our barometric measurements.

It is reported that since we left St. Vincent the amount of water in the crater has increased; and should this continue, a lake will ultimately be formed not unlike that which previously existed there. When the cliffs which form the north wall have reached, by repeated rock falls, a condition of adjustment and stability, and when vegetation has again covered the interior slopes, it is possible that the crater of the Soufrière will have regained very much of its old appearance. Should anyone who knew it before then return to visit it, he will have difficulty in believing that it formed the orifice from which were

emitted the tremendous explosions of May 7, 1902. It was, as we saw it, an impressive spectacle, its naked, rugged walls of rock looking down on the steaming lakes below.

Apart from the changes which have taken place within the crater and the deposits of ash which have formed in the river valleys and on the surface of the hill, the only other important geological modification of the country has been the disappearance of a narrow strip of coast along the leeward side of the island. Near the mouth of the Wallibu, and from thence northward to Morne Ronde, the sea has encroached on the land for perhaps 200 yards. Below Wallibu plantation there stood a village of laborers' huts on a low, flat beach with a bluff behind. Here the sea now washes the foot of a cliff some 30 feet high. This cliff consists of soft tuffs covered with several feet of new, hot ashes, and is in an unstable condition, as masses are constantly falling down from its face. In this way a new beach is now forming in front of it. It is agreed by those who knew the district before the eruption that not only has the old beach disappeared, which carried the village and the public road, but that part of the bluff behind has also subsided. We were informed by Mr. T. M. McDonald, who is intimately acquainted with this coast line, that similar subsidences had also taken place, though on a much smaller scale, at several places farther north. There is no evidence elsewhere of any changes of level of land and sea. The tide marks on the rocks and the landing stages at the villages enabled us to ascertain that the level of high water was at any rate within a few inches of what it had been before. It was clear that the alterations in the coast line were due to local subsidence of the foreshores, and that they had mostly affected loose and ill-consolidated deposits, such as beach gravels and the fans of alluvium which had formed at the mouths of the streams.

The submarine slopes on the leeward side of St. Vincent are very steep, averaging about 1 in 4. Often within half a mile of the shore, or sometimes even less, the depth is over 100 fathoms. It seems most probable that, owing to the concussions and earthquakes produced by the explosions, some of the less coherent accumulations on these steep slopes slipped bodily into the deep. On this supposition most of the facts would be explained, but at the same time it is possible that at Wallibu the inner margin of the depressed tract may be a fault line. It has a very straight trend, and it is a curious fact that this shore was formerly known as Hot Waters. This might indicate the existence of a fissure up which hot springs were rising.

When we arrived at Martinique we had the pleasure of meeting Professor Lacroix, the head of the French scientific commission, which had spent some time in making a preliminary survey of Mont Pelée and the north end of the island, and from him we obtained much valuable information regarding the sequence of events and the geological

consequences of the eruptions in that quarter. It was our intention to make merely such reconnoissances as would enable us in a general way to ascertain the points of difference and of similarity between the outburst of Mont Pelée and that of the Soufrière and to see what light the phenomena in Martinique threw on the events which had happened in St. Vincent.

Both volcanoes are of the same type, simple cones with a large vent near the summit, and without parasitic craters. They are both deeply scored with ravines, and on their southwest sides there is a broad valley occupied at Martinique by St. Pierre City; at St. Vincent by the Wallibu. It is in these valleys that the destruction has been most pronounced. In both, the recent eruptions have been characterized by paroxysmal discharges of incandescent ashes and a complete absence of lava streams.

In St. Vincent, however, the mass of material ejected has been much greater, and a considerably larger area of country has been devastated than in Martinique. That the loss of life was not so great can be accounted for by the absence of a populous city at the foot of the mountain. Had St. Pierre been planted at the mouth of the Wallibu Valley, there can be no doubt it would have been no less completely destroyed.

On Mont Pelée we understand that a fissure has opened on the south side of the mountain between the summit and St. Pierre, from which the blast was emitted which overwhelmed the city. But on the Soufrière the old orifices have been made use of. The eruption of Pelée began with the flow of mud lavas, but none such were seen in St. Vincent. On the other hand, the hot blast which swept down on the devoted city was essentially similar to that which we have described as having taken place at the Soufrière. Both eruptions produced principally hot sand and dust with a small proportion of bombs and ejected blocks. The evidence of the captain of the *Roddam* and of the survivors of the *Roraima* affords a very good idea of what happened in St. Pierre on May 8. An avalanche of incandescent sand was launched against the city. In the north end, which was nearest the crater, the inhabitants were instantaneously killed, the walls of the houses leveled with the ground, and the town was ablaze in a moment. In the south end the ruin was less. Those walls of the houses which faced the crater were demolished; those which ran north and south still stood, even when we were there, after the second eruption. In this quarter also all were killed, except a prisoner who was confined in an ill-ventilated cell in the prison, but we were told that for some minutes after the blast had passed people were seen rushing about in the streets, crying aloud with pain, and many threw themselves into the sea to escape the agony of their burns. It must be remembered that a terrible conflagration followed the eruption, and for thirty-six

hours the city was a burning pile. Another eruption followed on the 20th, and cast down many of the buildings which were left. Hence it was difficult to be sure exactly what were the effects of the volcanic blast, and what had to be ascribed to the conflagration. But we saw enough to satisfy us that the hot blast was probably no less violent here than at St. Vincent. An iron statue of the Virgin, standing on a stone pedestal on the wooded cliff overlooking the town, had been broken off and carried 40 feet away. It lay with the head pointing to the mountain, and the direction of the statue showed that the blast was traveling straight from the crater over the city. The cannon in the fort had been overthrown and had fallen away from the mountain, that is to say, in the same direction as the statue. The projecting ironwork of the verandas of the houses was twisted and bent. The light-houses were razed. The ships riding at anchor in the harbor were lying side-on to the blast. Some were capsized, others had their rigging cut clean away; only the *Roddam* escaped, and she was near the south end of the town. It was said that one man was blown clean off the *Roraima*. The trees which were growing in the streets were uprooted and cast down. Many of them showed charring and sand-blast erosion on the side which faced the crater, while the lee side was still covered with the original bark.

During the minute or two which this blast lasted, so much dust fell on the *Roddam* that Captain Ford, the harbor master at St. Lucia, estimated that 120 tons were removed from her decks when she arrived there, and the chief engineer of the R. M. S. *Esk*, who inspected her for Lloyd's, told us that the depth of the layer of ash was in some places 2 or 3 feet. Enough has been said to indicate the general similarity of the volcanic phenomena in Martinique and in St. Vincent. A fuller comparison, and more particularly the investigation of the outstanding points of difference, is best deferred till the detailed results of the French commissioners' investigations are to hand.

We were fortunate in having an opportunity of witnessing one of the more important eruptions of Mont Pelée before we left Martinique, and this enabled us to see how far the actual phenomena corresponded with the ideas we had been led to form from an inspection of the effects of the earlier outbursts. On the 9th of July we were in a small sloop of 10 tons, the *Minerva*, of Grenada, which we had hired to act as a convenient base for our expeditions on the mountain. The morning was spent in St. Pierre City and among the sugar-cane plantations on the lower slopes of the mountain, on the banks of the Rivière des Pères. The volcano was beautifully clear. Every ravine and furrow, every ridge and crag, on its gaunt, naked surface stood out clearly in the sunlight. (See pl. I.) Thin clouds veiled the summit, but now and then the mist would lift sufficiently to show us the jagged, broken cliff which overlooks the cleft. From the triangular fissure which serves

as the crater hardly a whiff of steam was seen to rise, and the great heap of hot bowlders which lies on the north side of and above this fissure could be perfectly made out. (See pl. II.) Small landslides took place in it occasionally, and small jets of steam rose now and again from between the stones.

A little after midday large steam clouds began to rise, one every ten or twenty minutes, with a low rumble. As they rose they expanded, becoming club-shaped, and consisting of many globular rolling masses, constantly increasing in number and in size as they ascended in the air. They might be compared to a bunch of grapes, large and small, or to a gigantic cauliflower. When their upward velocity diminished they floated away to leeward, and fine ash rained down in a dense mist as they drifted over the western side of the mountain. They occasioned no anxiety in our minds, as we had found that the mountain was never long without exhibiting these discharges, and they were due merely to an escape of steam, carrying with it fine dust. They rose, as a rule, to heights of 5,000 or 6,000 feet above the sea.

That afternoon, as the sun was getting lower in the heavens and the details of ravine and spur showed a contrast of light and shadow which was absent at midday, we sailed along from St. Pierre to Prêcheur, intent on obtaining a series of general photographs of the hill. The steam puffs continued, and about 6 o'clock, as we were standing back across the Bay of St. Pierre, they became more numerous, though not much larger in size. We ran down to Carbet, a village 1½ miles south of St. Pierre, where there is a supply of excellent water and good anchorage. About half past 6 it was obvious that the activity of the mountain was increasing. The cauliflower clouds were no longer distinct and separate, each following the other after an interval, but arose in such rapid succession that they were blended in a continuous emission. A thick cloud of steam streamed away before the wind, so laden with dust that all the leeward side of the hill and the sea for 6 miles from the shore was covered with a dense pall of fine falling ash. (See pl. III.) The sun setting behind this cloud lost all its brightness and became a pale yellowish-green disk, easily observable with the naked eye. Darkness followed the short twilight of the Tropics, but a four days old moon shed sufficient light to enable us to see what was happening on the hillside.

Just before darkness closed in we noticed a cloud which had in it something peculiar hanging over the lip of the fissure. At first glance it resembled the globular cauliflower masses of steam. It was, however, darker in color, and did not ascend in the air or float away, but retained its shape, and slowly got larger and larger. After observing it for a short time we concluded that it was traveling straight down the hill toward us, expanding somewhat as it came, but not rising in the air, only rolling over the surface of the ground. It was so totally

distinct in its behavior from the ascending steam clouds that our attention was riveted on it, and we were not without apprehension as to its character. It seemed to take some time to reach the sea (several minutes at least), and as it rolled over the bay we could see that through it there played innumerable lightnings. We weighed anchor and hoisted the sails, and in a few minutes we were slipping southward along the coast with a slight easterly wind and a favorable tide.

We had, however, scarcely got under way when it became clear that an eruption was impending. As the darkness deepened, a dull red reflection was seen in the trade-wind cloud which covered the mountain summit. This became brighter and brighter, and soon we saw red-hot stones projected from the crater, bowling down the mountain slopes, and giving off glowing sparks. Suddenly the whole cloud was brightly illuminated and the sailors cried, "The mountain bursts!" In an incredibly short space of time a red-hot avalanche swept down to the sea. We could not see the summit, owing to the intervening veil of cloud, but the fissure and the lower parts of the mountain were clear, and the glowing cataract poured over them right down to the shores of the bay. It was dull red, with a billowy surface, reminding one of a snow avalanche. In it there were larger stones which stood out as streaks of bright red, tumbling down and emitting showers of sparks. In a few minutes it was over. A loud, angry growl had burst from the mountain when this avalanche was launched from the crater. It is difficult to say how long an interval elapsed between the time when the great glare shone on the summit and the incandescent avalanche reached the sea. Possibly it occupied a couple of minutes; it could not have been much more. Undoubtedly the velocity was terrific. Had any buildings stood in its path they would have been utterly wiped out, and no living creature could have survived that blast.

Hardly had its red light faded when a rounded black cloud began to shape itself against the star-lit sky exactly where the avalanche had been. The pale moonlight shining on it showed us that it was globular, with a bulging surface, covered with rounded protuberant masses, which swelled and multiplied with a terrible energy. It rushed forward over the waters, directly toward us, boiling, and changing its form every instant. In its face there sparkled innumerable lightnings, short, and many of them horizontal. Especially at its base there was a continuous scintillation. The cloud itself was black as night, dense and solid, and the flickering lightnings gave it an indescribably venomous appearance. It moved with great velocity, and as it approached it got larger and larger, but it retained its rounded form. It did not spread out laterally, neither did it rise into the air, but swept on over the sea in surging globular masses, corruscating with lightnings.

When about a mile from us it was perceptibly slowing down. We then estimated that it was 2 miles broad and about 1 mile high. It

began to change its form; fresh protuberances ceased to shoot out or grew but slowly. They were less globular, and the face of the cloud more nearly resembled a black curtain draped in folds. At the same time it became paler and more gray in color, and for a time the surface shimmered in the moonlight like a piece of silk. The particles of ash were now settling down, and the white steam, freed from entangled dust, was beginning to rise in the air.

The cloud still traveled forward, but now was mostly steam, and rose from the surface of the sea, passing over our heads in a great tongue-shaped mass, which in a few minutes was directly above us. Then stones, some as large as a chestnut, began to fall on the boat. They were followed by small pellets, which rattled on the deck like a shower of peas. In a minute or two fine, gray ash, moist and clinging together in small globules, poured down upon us. After that for some time there was a rain of dry, gray ashes. But the cloud had lost most of its solid matter, and as it shot forward over our heads it left us in a stratum of clear, pure air. When the fine ash began to fall, there was a smell of sulphurous acid, but not very marked. There was no rain.

The volume of steam discharged must have been enormous, for the tongue-shaped cloud broadening, as it passed southward, covered the whole sky except a thin rim on the extreme horizon. Dust fell on Fort de France and the whole south end of Martinique. The display of lightning was magnificent. It threaded the cloud in every direction in irregular branching lines. At the same time there was a continuous low rumble overhead.

What happened on Mont Pelée after this discharge can not be definitely ascertained. For some hours afterwards there were brilliant lightnings and loud noises which we took for thunder. That night there was a heavy thunder storm over the north end of Martinique, and much of the lightning was atmospheric, but probably the eruption had something to do with it, and the noises may have been in part of volcanic origin.

There can be no doubt that the eruption we witnessed was a counterpart of that which destroyed St. Pierre. The mechanism of these discharges is obscure and many interesting problems are involved, but we are convinced that the glowing avalanche consisted of hot sand and gases, principally steam; and when we passed the hill in R. M. S. *Yare* a few days later we had, by the kindness of the captain, an excellent opportunity of making a close examination of the shore from the bridge of the steamboat. The southwest side of the hill, along the course of the Rivière Sèche, was covered with a thin coating of freshly fallen fine gray ashes, which appeared to be thickest in the stream valleys. The water of the rivers flowing down this part of the hill was steaming hot. This was undoubtedly the material emitted from the crater on

the night of the eruption. There was no lava. We saw no explosions of combustible gases and nothing like a sheet of flame. We were agreed that the scintillations in the cloud were ordinary lightnings, which shot from one part of its mass to another, and partly also struck the sea beneath.

The most peculiar feature of these eruptions is the avalanche of incandescent sand and the great black cloud which accompanies it. The preliminary stages of the eruption, which may occupy a few days or only a few hours, consist of outbursts of steam, fine dust, and stones, and the discharge of the crater lakes as torrents of water or of mud. In them there is nothing unusual, but as soon as the throat of the crater is thoroughly cleared and the climax of the eruption is reached, a mass of incandescent lava rises and wells over the lip of the crater in the form of an avalanche of red-hot dust. It is a lava blown to pieces by the expansion of the gases it contains. It rushes down the slopes of the hill, carrying with it a terrific blast which mows down everything in its path. The mixture of dust and gas behaves in many ways like a fluid. The exact chemical composition of these gases remains unsettled. They apparently consist principally of steam and sulphurous acid. There are many reasons which make it unlikely that they contain much oxygen, and they do not support respiration.

After visiting Martinique we proceeded to Dominica, where Dr. Flett visited the Soufrière at the south end of the island and the famous Boiling Lake and Grand Soufrière. There have been few signs of increased volcanic activity here or in St. Lucia during the recent eruptions. Dr. Tempest Anderson spent some days in Grenada in an examination of the lagoon at St. Georges, but particulars regarding these islands may be reserved till a fuller report appears.

DESCRIPTION OF THE PLATES.

PLATE I.—*Mont Pelée from the west.*—Taken from the sea near Prêcheur, a village north of St. Pierre. This view shows how the mountain is cut up into deep ravines by the tropical rains. Part of the summit is concealed by clouds, and the fissure from which the eruption was proceeding was apparently behind and to the right of the small central peak in the background.

PLATE II.—*Mont Pelée from the southwest.*—This photograph was taken from the sea off the mouths of the Rivière Sèche and Rivière Blanche, which are about 2 miles north of St. Pierre. It shows the rugged character of the mountain, the summit of which is concealed by clouds. The slope in the foreground is the track of the avalanches which descended from the triangular (dark-colored) fissure to the right of the central peak.

PLATE III.—*Mont Pelée in eruption.*—Taken from a sloop off St. Pierre on the afternoon of July 9. It shows the "cauliflower" shapes assumed by the clouds of dust and steam as they drifted westward out to sea. The lighter-colored cloud to the east (or right) is the trade-wind cloud which so constantly covered the summit. A small light-colored cloud patch just below this, on the right-hand (eastern) side, indicates the fissure from which the eruption chiefly proceeded. The eruptive "avalanche" of volcanic material descended the slopes in the center and rather to the left of the foreground. St. Pierre is to the right, outside the picture.



MONT PELÉE IN ERUPTION.



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OUTBURST OF DUST-LADEN STEAM AT THE MOUTH OF THE WALLIBOU RIVER, ST. VINCENT.

From a sketch by George Carroll Curtis. "These outbursts were the result of the mingling of the waters of the river, swolen by tropical downpours, with the hot ash beds of the May eruptions. This particular outburst took place about 5 p. m. May 30, 1902."—Curtis.

VOLCANIC ERUPTIONS ON MARTINIQUE AND ST. VINCENT.[a]

By Israel C. Russell,

Of the National Geographic Society Expedition to West Indies.

The continuation of activity in the case of Mont Pelée and La Soufrière of St. Vincent makes it evident that it is yet too early to write a final report on their recent eruptions. What may be termed a first approximation, however, to the significance of the observations concerning them already in hand,[b] may be of interest to the members of the National Geographic Society.

The number of active craters.—The first question to which an answer is sought concerning both Mont Pelée and La Soufrière is: Have the recent eruptions occurred from a single and essentially a summit crater in each instance, or have secondary or subcraters been opened on the sides of the volcanoes, which had a connection with their conduits? In the case of La Soufrière no differences of opinion in this connection have arisen among the several observers who have visited the mountain. The eruptions have all occurred in a single crater, the so-called old crater, in distinction from the one formed in 1812. This crater is near the summit of the mountain, but is partially encircled on the northeast by a remnant of a much older and far larger crater, which corresponds with Mont Summa at Vesuvius, and may be termed a "somma."

At Mont Pelée there is also a somma, and on its southwest side is the crater known as Étang Sec, which is now in eruption. A smaller summit crater, formerly occupied by Lac des Palmistes, occurs to the northeast of the one now active, and corresponds in a general way with the crater of 1812 on St. Vincent. While several observers have reported the existence of at least two subcraters—one on the east and the other on the southwest slope of Mont Pelée, the former termed the "Falaise crater" and the latter the "Rivière Blanche crater"—a careful consideration of the evidence presented fails to show that these are true centers of eruption having deep

[a] Reprinted by permission, after revision by the author, from the National Geographic Magazine, Vol. XIII, No. 12, December, 1902.

[b] A list of the papers referred to is presented at the end of this essay.

sources. Great explosions have occurred, however, at each of the localities referred to, which have thrown large quantities of dust and mud to a height of several hundred feet, and sent out vast volumes of steam to a height of many thousands of feet; but these phenomena are seemingly the same, although marked by greater energy, as have been observed in a large number of instances on both Martinique and St. Vincent, where the hot dust, lapilli, stones, etc., ejected from the summit crater in each instance, have accumulated to a great depth and been invaded by surface water. While the suberaters mentioned should not, in my opinion, be considered as true volcanoes, they simulate many of the phenomena attending actual eruptions from deep conduits. The columns of steam, heavily charged with dust and mud, which arise from them have the convoluted or cauliflower structure, and at times expand at the top and take on mushroom shapes in much the same manner as do the columns of steam similarly charged with rock fragments that are blown into the air from a primary crater. In each case the proximate cause is the same, namely, a steam explosion. The solid material blown into the air in each instance is also of the same nature for the reason that the hot dust and stones, to which the superficial explosions are due, were supplied by the eruption of the summit crater. Since the observed phenomena are so similar, it may be asked: What is the crucial test by which a true crater may be distinguished from a pseudocrater? To formulate a definite answer to this question is difficult. Perhaps the best reply that can be offered is that the pseudocraters are later in the time of their appearance than the main eruptions which supplied the hot material necessary for their production, and that they occur when the topographic conditions previous to the eruptions favored the accumulation of a deep deposit of hot débris. In addition, on both Martinique and St. Vincent a complete gradation in size and energy of the superficial steam explosions has been observed, ranging from small geyser-like spoutings (Pl. I), such as have occurred at hundreds of localities in valleys that were deeply filled with hot débris, and even on broad and comparatively smooth surfaces covered with a thick sheet of similar material, up to the markedly energetic explosions in the valleys of the Falaise and Rivière Blanche. In many instances the smaller surface explosions have been observed to follow heavy rains, and the same is true also of the larger explosions referred to. The main explosions from the summit craters have not only been vastly more energetic than any that have occurred at the sites of the pseudocraters, but the débris blown out was incandescent, while the material thrown into the air by the explosions in the hot accumulations in the river valleys has not been observed to be even red hot. The minor eruptions from the summit crater, however, may be due to precisely the same immediate cause as the eruptions of the pseudocraters—namely, the access of

surface water to highly heated rocks, so that an apparently complete sequence may be observed between the escape of steam from hot débris and the discharges from true volcanic conduits. It is thus seen that the discovery of the crucial test asked for is difficult, and the final decision, if one is reached, must rest on a judicial balancing of all the evidence and the weight to be given to the judgment of individual observers. An instructive fact furnished by the pseudocraters (even when the larger and, as some persons may think, questionable examples are not considered) which has a bearing on the theories of the ultimate causes of volcanic eruptions is the close similarity and, in fact, identity that exists between the explosions due to surface water gaining access to beds of hot débris and the explosions during primary eruptions in the summit portions of true volcanic conduits. In the former instances surface water descends into hot-rock débris; and, from the fact that water is present in the superficial portion of the earth's crust, it seems equally manifest in the latter instance that highly heated rock rises from deep within the earth and meets the surface waters. In each instance steam explosions result.

The conditions favoring the occurrence of pseudo-eruptions and the character of the topographic changes produced by them are clearly shown in the sketch and section forming fig. 2, Pl. II, which accompanies an instructive article on the "Secondary Phenomena of the West Indian Volcanic Eruptions," by G. C. Curtis,[a] published since the present essay appeared. Some of the secondary craters, or "ash-geyser cones," on Martinique and St. Vincent are stated by Curtis to be 40 feet high and 160 feet in diameter, with slopes averaging 25° to 30°.

Variation in the eruptions of the primary craters.—The variations presented by the steam columns that ascend from active volcanoes—of which the so-called pine tree of Vesuvius is a well-known example—and which in many instances afford the most spectacular of the awe-inspiring phenomena associated with them, have been described by several observers who have recently visited Martinique and St. Vincent, but most graphically by George Kennan. The variations referred to are indicative of what takes place in an active crater and in the upper part of the conduit leading to it, and furnish evidence in reference to the changes there in progress. A classification of the various phases presented by the steam column rising from Mont Pelée has been presented by the gifted traveler just referred to, which is instructive:

"The vapor column ascending from Mont Pelée," writes Kennan, "varies greatly from day to day and sometimes from hour to hour, not only in density, but in color, form, and general appearance. In its varying aspects it may be described as follows:

"1. The vapor of quiescence: A slowly ascending column of pure

[a] The Journal of Geology, Vol. XI, February-March, 1903, pp. 199–215.

white steam, which has neither sharp, clearly defined outlines, nor puff-like convolutions, and which suggests steam rising from the hot water of a geyser basin or from the escape pipe of a big ocean steamer."

The explanation of the occurrence of such a column from a crater of the type of the one at the summit of Mont Pelée, a sketch of which by Varian is herewith given (fig. 1, Pl. II), seems to be that the top of the lava column is well below the bottom of the crater, and that the hot rocks are discharging steam, owing to the contact with them of water percolating in from the crater walls or falling as rain. The generation of steam is a surface phenomena, and due essentially to the same cause as the escape of steam from hot débris ejected by a volcano and accumulating in valleys, etc. The notable feature is the absence of convolutions and more or less individualized fleece-like masses in the ascending column, such as are produced by small steam explosions from liquid lava, as is frequently the case at Vesuvius.

"2. The vapor of moderate activity: A column of greater density and somewhat darker color, which rolls and unfolds a little as it rises, and looks like steam mixed with brownish or yellowish smoke from the chimney of a manufactory."

This stage may reasonably be supposed to indicate conditions similar to those mentioned in the first instance, but more intense. A considerable volume of water gaining access to the deep funnel-shaped crater might not be vaporized before descending to the summit of the column of liquid or but partially congealed column of rock within the conduit, and energetic explosions result. The steam columns indicative of moderate activity thus correspond with the columns produced by the maximum explosions of pseudo-craters. The inner slope of the crater of Mont Pelée is precipitous, and, as several observers have reported, portions of its walls overhanging. The fall of blocks of rocks from the crater walls would no doubt cause a conspicuous column of dust-laden steam to ascend.

"3. The vapor of dangerous activity: A sharply defined dark-yellow column of what appears to be liquid mud, which boils out of the volcano in huge, rounded masses, swelling and evolving in immense convolutions as it rises—one gigantic mud bubble breaking up out of another in turn—until over the crater there stands a solid opaque pillar of boiling, unfolding, evolving mud vapor 500 feet in diameter and eight or ten thousand feet in height."

The appearance of the volcano during the stage here described is illustrated by sketch by Varian, forming Pl. IV, and by fig. 1, Pl. III. When such a débris-charged steam column rises from a crater there is no question as to the presence of a conduit leading down deep into the earth. The pseudo-craters never reach such intensity.

"4. The vapor of great eruptions: A straight-sided shaft of very black smoke (dust-charged steam), which shoots up out of the crater

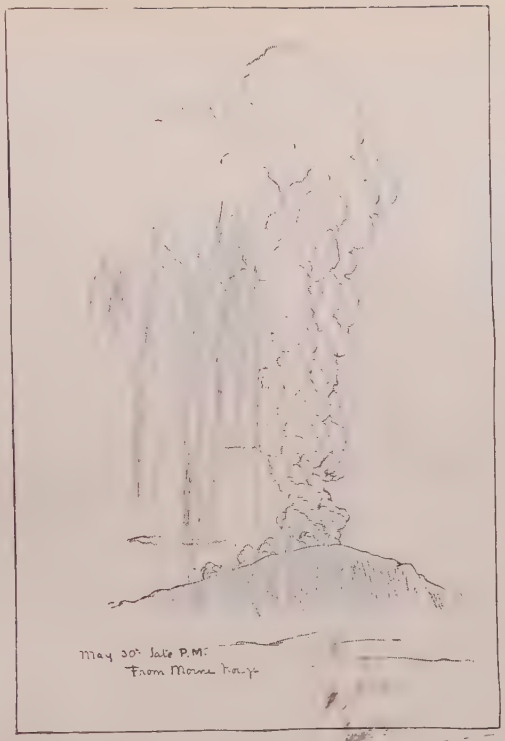


FIG. 1.—"VAPOR OF QUIESCENCE" ~~RISING~~ FROM MONT PELÉE ON MAY 30 TO A HEIGHT OF 6 MILES.

Drawn by George Varian. Republished from McClure's Magazine.

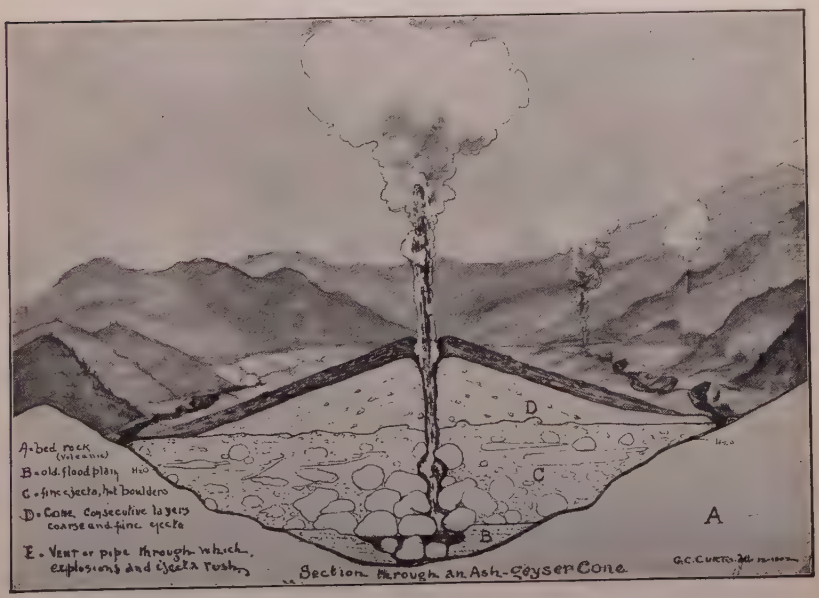


FIG. 2.—SECTION THROUGH AN ASH-GEYSER CONE.

After George Carroll Curtis. A, Bed-rock; B, old flood plain; C, fine ejecta, hot bowlders, etc.; D, cone composed of consecutive layers of coarse and fine ejecta; E, vent or pipe through which steam explosions accompanied by ejecta occur.



FIG. 1.—MONT PELÉE IN ERUPTION, MAY 28, 1902.

From a photograph by George Kennan taken at Assier. Republished from The Outlook of August 2, 1902.



FIG. 2.—"BREAD-CRUST" VOLCANIC BOMB, MONT PELÉE.

Height of specimen, 2 feet 2 inches. From a photograph by E. O. Hovey. Republished from the Bulletin of the American Museum of Natural History.

with a tremendous velocity, like the smoke of a collossal piece of artillery fired heavenward. This shaft goes to a height of fifteen or twenty thousand feet, and then mushrooms out laterally, so as to cover a circle 50 miles or more in diameter, with a volcanic canopy which is as dark as the blackest thunder cloud and which shuts out the light of day like a total eclipse. The projectile force in eruptions of this kind is so great that it throws the black vapor far above the influence of the trade winds, and the advancing edge of the volcanic mantle moves swiftly eastward 2 miles or more above the fleecy trade-wind clouds that are drifting in the opposite direction."

Something of the terrifying grandeur of a great eruption described above is suggested by a sketch forming Pl. V. In the making of such a column the volume of water and of comminuted rock required is enormous. The volume of the column is in the neighborhood of 4,000,000,000 cubic feet.

If 1 per cent of the column is solid matter, it equals 40,000,000 cubic feet—equals 3,000,000 tons.

If 10 per cent of the column is solid matter, it equals 400,000,000 cubic feet—equals 30,000,000 tons.

To be sure, we have no accurate measures, our information being almost entirely qualitative; but as such a column as is referred to has been observed to reach a height by estimate of 10,000 feet in two minutes, it may seemingly be safely assumed that it reached its full development in less than five minutes. The coarser of the solid matter first shot out then begins to fall, and the form of the column is maintained by new matter driven upward from the crater. Thus during each five minutes of an eruption some 4,000,000,000 cubic feet of débris-laden steam were expelled from the crater. The average duration of such eruptions is not known, but in certain instances they continued for a considerable fraction of an hour. During each hour that Mont Pelée or La Soufrière was in full blast something like 48,000,000,000 cubic feet of dust and stone laden steam were driven out. Only guesses can be made as to the amount of solid matter the steam contained. Shall we assume 1 per cent or 10 per cent? Most observers would agree, I fancy, not only that the latter was nearer the truth than the former estimate, but that the true measure is in excess of the larger of the two.

The material extruded in a solid condition, as will be shown later, is fresh lava which came from deep within the earth; but mingled with it are rock fragments that were torn from the walls of the conduits through which the discharges occurred. The per cent of old lava among the ejected solids seems to be greater on St. Vincent than on Martinique. In harmony with this is the larger size of the crater of La Soufrière in comparison with that of Mont Pelée.

The columns of steam of Kennan's type No. 4 thus show that great volumes of rock are rising from deep within the earth and being blown

into the air. If, as seems probable, the energy displayed by steam columns of the No. 2 type is all than can be supplied by the steam produced from rain and percolating water in the upper part of the conduit, it follows that during explosions of the No. 3 type both rock and steam are rising from a depth in the volcanic conduits. Presumably, then, during eruptions of the types No. 3 and No. 4 molten rock is being forced up within the conduit of a volcano and, owing to relief of pressure as it rises, the steam dissolved in the molten magma escapes with tremendous violence. There are thus two sources for the steam which furnish the energy displayed in the summit portions of ascending lava columns—one from the rain and percolating water, and the other from a deeper but unknown source. But this attempt to follow the volcanic conduits downward in fancy has brought us to the region of speculation and it is time to stop, at least for the present.

To the four types of volcanic-steam columns described above, a fifth might be added to include volcanic explosions like that of Krakatoa.

Products of the eruptions.—The material discharged from Mont Pelée and La Soufrière may be divided into two portions—first, steam and gases, and, second, solid rock débris. Up to the present time no observations indicate that molten rock has been extruded; that is, no lava streams have flowed over the surface from the crater of either volcanoes or issued from fissures in their sides.

As to the discharge of vast volumes of steam, there is no difference of opinion to be formed in the various reports already rendered. Observers who have visited the craters from which the recent eruptions came, and have even ventured within them, report only faint traces of gases. The conditions, however, between the time when a crater is quiescent and when violent explosions occur within it are no doubt different, and as yet but little evidence concerning the gases that may have been present during the times of most violent activity has been obtained. The most that can be accepted in this connection is a plainly perceptible odor of sulphurous acid noticeable in the air, even at a distance of some 8 miles at sea, when the volcanoes were in a comparatively mild state of activity and while walking over the débris they showered on their respective islands. A much fainter odor of sulphuretted hydrogen is reported to have been present, as, for example, among the ruins of St. Pierre, but whether due to gas emitted from the volcano or arising from organic matter buried beneath the still hot débris is not clear. The presence of carbon dioxide, although asserted or surmised to have been discharged during the greater eruptions, has not been proven. The consideration of all the available evidence points strongly to the conclusion that steam was the chief vaporous or gaseous substance emitted, but mingled with it were minor quantities of sulphurous and no doubt other gases.

In the above connection it should be noted that flames above the



MONT PELÉE FROM VIVÉ, MAY 27.

The great cloud of steam and smoke rose cauliflower-shaped from the summit crater to a height of from 2 to 3 miles. The descending shower of rain and ashes shows on the right. Drawn by George Varian. Republished from McClure's Magazine.



THE NIGHT ERUPTION OF MONT PELÉE AS SEEN FROM THE ROAD GOING SOUTH FROM VIVÉ TOWARD ASSIER.

Drawn by George Varian. Republished from McClure's Magazine.



MONT PELÉE FROM THE WEST.



MONT PELÉE FROM THE SOUTHWEST.

summit of both Mont Pelée and La Soufrière have been reported by several trustworthy witnesses. If the appearances referred to were in reality flame, and not glowing dust or the reflection of the light from incandescent rocks on vapor, it is evident that inflammable gases were present. No spectroscopic observations seem to have been made, however, and until this is done the evidence as to the presence of inflammable gases in notable quantity must be received with caution.

The reports that Mont Pelée and La Soufrière discharged mud are probably correct so far as would appear from a distance, yet the true meaning would seem to be that such eruptions were of the nature of the explosions in the pseudo-crater or in the true craters during intervals between the eruptions from a deep source. Hot dust and lapilli accumulating in a crater during quiescent stages would furnish most favorable conditions for the producing of superficial explosions where rain occurred or springs entered a crater from its sides, as has been observed, and would produce eruptions similar to those of the pseudo-crater, and mud flows might result. It is evidently not to be inferred that either of the volcanoes in question has erupted mud from a deeply seated source.

The solid matter discharged from Mont Pelée and La Soufrière is almost entirely in the condition of angular fragments varying in size from those weighing in the neighborhood of 1,000 tons to the finest of dust particles. The fragmental material is of two classes: First, fragments of the rocks torn from the walls of the conduits through which the upward rush of débris-charged steam occurred; and, second, fragments of hardened lava which had been forced upward into the conduits in a plastic condition and shattered and blown out by the escaping steam. In addition to the angular fragments of fresh lava, minor quantities of more or less spherical masses of similar material, which were projected into the air while yet moderately plastic, have also been observed. While the term volcanic bomb has been applied to much of the ejected material, it is evident that only the somewhat spherical masses referred to deserve to be so called, and even in such instances there is doubt as to the propriety of using the term. Typical volcanic bombs have a round or oval form, with extended and spirally twisted projections at the ends of the longer axis, the spherical or more commonly oval form and the spirally twisted extremities being due to the rotation of the mass during its aërial flight and while yet plastic. No projectiles answering this description have as yet been reported as occurring on Martinique or St. Vincent. The nearest approach to a characteristic bomb are certain rudely spherical masses of lava with cracked surfaces (fig. 2, Pl. III) and without projections or indications of a spiral twist. Evidently these poorly shaped bombs are composed of fresh lava which was sufficiently hot to make it somewhat plastic at the time it was blown into the air, but was too

rigid to acquire the typical shape frequently to be seen in large numbers of bombs about certain basaltic craters.

The absence of characteristic bombs on Martinique and St. Vincent is in keeping with the composition of the lava thrown out. The fresh lava is an andesite, having in a general way the composition of a refractory brick, and unless very highly heated would not be plastic. The dark color of the columns of steam rolling up from the craters when in violent eruption, and the vast quantities of fragmental material showered on the adjacent land and sea is evidence that as molten rock was forced up the volcanic conduits it became cooled and stiffened before reaching the summits of the volcanoes and was shattered by steam explosions, and the fragments blown into the air. Not only are true volcanic bombs absent, but clots and splashes of plastic or fluid rocks, such as are common about many volcanoes that have erupted easily fusible material, are also lacking.

The fragments ejected were in many instances blown to a height of many thousands of feet, the finer lapilli and dust being carried perhaps 5 or 6 miles high, and on falling were distributed in part through the influence of the winds, in a general way in reference to size and weight. The larger and heavier masses fell near the craters from which they were projected, while much of the finer and lighter material was carried great distances. Variations in the method of distribution were caused by the direction of the hurricane-like blasts which swept down from bothMont Pelée and La Soufrière during their mightier eruptions, by the direction of the trade winds and upper-air currents, and by tornado-like swirls in the greatly disturbed atmosphere. Immediately following each great eruption, also, there was a strong indraft of cool air from about the region covered with hot débris. The vastness of the area on which the ejected material fell is indicated by the fall of dust on Barbados, Trinidad, and on ships 275 miles southeast of St. Vincent.

Observations reported by E. O. Hovey show that, contrary to earlier accounts, written in part by myself, coarse material fell in St. Pierre. The riddling of boiler plates one-fourth inch thick (Pl. VI), in the northern portion of the stricken city, by stone shot against them from Mont Pelée, is evidence that the hurricanes of steam charged with hot dust, which swept down from that volcano on May 8 or May 20, and perhaps during later eruptions, were accompanied by a bombardment of stones, no doubt hot, which were as deadly as solid shot fired from a cannon.

Causes of death.—Respecting the general cause of death in St. Pierre, the reports of various observers differ more widely than in connection with any other occurrence associated with the eruption of Mont Pelée, unless it be in reference to the secondary craters referred to above. Obviously many deaths occurred in St. Pierre from the



FIG. 1.—ST. PIERRE. RUINS OF THE GREAT DISTILLERY IN THE FORT QUARTER OF THE CITY, SHOWING HOLES IN THE IRON TANKS DUE TO VOLCANIC BOMBARDMENT.

From a photograph by E. O. Hovey. Republished from the Bulletin of the American Museum of Natural History.



FIG. 2.—ST. PIERRE. NEAR VIEW OF ONE OF THE HOLES SHOWN IN ABOVE FIGURE.

The material of the tanks is quarter-inch boiler iron. From a photograph by E. O. Hovey. Republished from the Bulletin of the American Museum of Natural History.



DEPOSIT OF VOLCANIC DUST ON FORMERLY CULTIVATED SLOPES, LOOKING SOUTH FROM MORNE D'ORANGE, MAY 21, 1902.

Photograph by Israel C. Russell.

bombardment of missiles that swept through the city, as just mentioned, from the falling of walls and other objects, from the fire that followed the volcanic blast, from nervous shock, etc.; but opinions differ as to the principal cause of the loss of life. The opinions referred to fall in two groups: (*a*) Those favoring the idea that gases were the deadly agency, and (*b*) those which refer the loss of life to the effects of steam charged with hot dust.

(*a*) Certain observers are strongly inclined to the opinion that Mont Pelée, or more accurately, the "Rivière Blanche subcrater," discharged gases which asphyxiated the inhabitants of St. Pierre. As to the nature of the supposed gases, at least two suggestions have been made — one that it was mainly sulphureted hydrogen, and the other, carbon dioxide or some similar gas. Coupled with the first of these suggestions is the further hypothesis that gas explosions took place within the city and added to the deadly effect of the asphyxiating gases. The hypothesis that gases were the direct cause of the greater part of the loss of life, as claimed at St. Pierre, has not, so far as I am aware, been extended to St. Vincent, but the dead and the injured on the two islands met their fate in precisely similar ways. The evidence bearing on the question under consideration has been judiciously discussed by George Kennan, and the testimony of the sole survivor of the disaster of May 8 placed on record. Had noxious gases, and especially such heavy ones as carbon dioxide and sulphureted hydrogen, been swept over the city in sufficient quantities to kill nearly all the inhabitants, it is evident that the occupant of a cell below the level of the adjacent street would have been in a most dangerous position. The testimony of the prisoner referred to, as summarized by Kennan, after a critical cross-examination, is that he "heard no explosions or detonations; saw no flame; smelled no sulphurous gas; and had no feeling of suffocation. He was simply burned by hot air and hot ashes which came into his cell through the door grating."

It is impracticable to review in this essay all the evidence which it is claimed sustains the hypothesis of asphyxiation by gases. This side of the discussion, however, has been well presented by R. T. Hill in the National Geographic Magazine, in the Century Magazine, and in Collier's Weekly, and by Angelo Heilprin[a] in McClure's Magazine. (See list at end of this essay.)

(*b*) The efficiency of steam charged with hot dust, or of either of these agencies alone, to cause scalds, burns, and even instantaneous death, is not open to doubt. The question is: Was the steam and hot dust swept over the portions of Martinique and St. Vincent at the time so many thousand people were killed the chief agency in their destruction? Cumulative evidence has been added to the various classes of

[a] Since this was written Heilprin has published his highly instructive book, Mont Pelée and the Tragedy of Martinique, in which the principal cause of death in St. Pierre, Morne Rouge, etc., is ascribed to dust-laden steam.

facts presented by me in the July number of this magazine,[a] which sustains conclusions then reached. I refer to the narrative of George Kennan published in the Outlook for August 16, the preliminary report made by Tempest Anderson and J. S. Flett to the Royal Society of London, and the preliminary report made by E. O. Hovey to the American Museum of Natural History. Although frankly confessing that I am not an unbiased judge of the printed testimony, yet it seems fair to claim that the evidence presented is conclusive as to the important part taken by steam and hot dust in the sudden destruction of the people of St. Vincent on May 7 and of the inhabitants of St. Pierre on May 8.

Downward volcanic blasts.—Intimately associated with the destruction of St. Pierre is the direction taken by the blast of dust-charged steam, with its volleys of stones, which swept over the city. The hypothesis that St. Pierre was destroyed by an eruption from the "Rivière Blanche subcrater" being rejected, and the further suggestion, based on the earlier reports in reference to the opening of a fissure in the side of the mountain, not finding support in later evidence, the way is cleared for a better understanding of the true cause of the direction taken by the down blast that came, as now seems definitely proven, from the Étang Sec, which is essentially a summit crater.

To understand the nature of the volcanic blast which destroyed St. Pierre, one needs to visit the region swept by a similar eruption on St. Vincent. The volcanoes on these two islands have not only shown a direct relationship in the times of their eruptions, but the surface phenomena exhibited by one is the counterpart of what took place in the case of the other. Happily on St. Vincent, however, there was no densely populated city within the radius of greatest destruction.

On St. Vincent the region throughout which the previously luxuriant vegetation, plantations, etc., were swept away or buried beneath hot dust and stones, encircles the mountain. The direction in which trees were swept down, and on the periphery of the devasted area the erosion of the bark of trees still standing, on the side facing the volcano, as well as much other evidence, show in a most conclusive manner that a blast charged with dust and stones swept down the slopes of La Soufrière in all directions. The influence of hills at a distance of some 4 or 5 miles from the volcano in shielding the vegetation on their slopes facing away from it shows that the topography of the

[a] It was impracticable for me to read the proof of the article referred to, and in the titles of some of the illustrations, especially, there are serious errors. In the title of the plate opposite page 278, "Georgetown" should be substituted for "Kingstown;" the title of the plate opposite page 282 should be "Valley of Wallibu River deeply filled with hot débris;" on page 284 the title of the illustration should "Summit of Morne d'Orange, St. Pierre." The map on page 282 fails to show the area at the north end of St. Vincent, as indicated on the original, which was not devastated, and is much generalized in other ways.—I. C. R.



South. North.

STATUE OF OUR LADY OF THE WATCH, MORNE D'ORANGE, SOUTH END OF ST. PIERRE.

This statue, weighing several tons, was hurled 50 feet by the terrific blast of May 8, 1902. Photograph by Israel C. Russell.



EASTERN PORTION OF THE CITY OF ST. PIERRE, MAY 21, 1902.

Photograph by Israel C. Russell.

land controlled, in a measure, the direction taken by the volcanic winds. The presence of a partially encircling ridge or somma, on the northeast side of the volcano, seemingly accounts for the escape from destruction of a narrow fringe about the northeast border of the island. The outward direction that the blast took from the mountain, its decreasing intensity with increase in the distance it traveled, and the absence of even hypothetical subcraters, all bear witness that the heavily dust and stone charged steam from the old crater near the summit swept downward and outward with hurricane force, in a similar way to the more localized blast from Mont Pelée which destroyed St. Pierre.

The one conspicuous feature of Mont Pelée which differs from anything on La Soufrière is the presence in the southwest portion of its active crater of a deep notch—the Fente or Terre Fendue—which, as stated by Heilprin, has been a conspicuous feature of the mountain since the eruption of 1851, and may have existed previous to that event. This cleft is in plain view from St. Pierre, and during my visit to the dead city one could look into it and plainly see the ruddy cone of eruption with its ascending steam column that was being built within the crater. The area rendered desolate by the hot blast from Mont Pelée on May 8, and again swept over by a similar blast on May 20, is fan-shaped, the apex of the triangle being essentially at the summit of the mountain. The coincidence between the position and direction of the Fente and the apex of the expanding volcanic blasts may well be considered significant. From the various accounts of the eruptions of Mont Pelée available, it now seems evident that the blasts which destroyed so much of the vegetation of Martinique and wrought havoc in St. Pierre came from the crater with a deeply notched rim, and that the direction taken by the blasts, at least on May 8 and May 20, was determined by that rift in the crater's rim.

As stated by T. A. Jaggar, the downward blasts from volcanoes do not require a horizontal nozzle to project them. "They are simply the result of the down blast after the heavy gravel has begun to fall, acting against the upblast from the throat of the volcano, and both together deflected and thrown into terrific whirls or tornadoes." This explanation, although briefly stated, may seemingly be taken as the leading cause of the downward sweep of the steam charged with rock fragments on both Mont Pelée and La Soufrière. It does not seem clear, however, that the down blasts occur only after a towering column of débris-charged steam has reached a great height and the fall of the heavier material within it has begun. Then, again, it may be asked why it is that every strong eruption is not followed by a down blast.

Variations in the character of volcanic eruptions of the type under consideration occur on account of variations in the energy of the

explosions and the degree to which the ascending steam is débris-charged. If the energy is great and the upward propelling force essentially constant, it may well be inferred that the column, as explained by Jaggar, will attain a great height before the resistance it offers to the ascent of fresh material causes an expansion at the base. If, however, the steam driven out at any stage in an eruption is excessively loaded with débris, an expansion and overflow at the rim of a crater might occur, no matter whether the fall of previously discharged material from aloft had begun or not. The essential feature in a down blast from a crater seems to be that heavily débris-charged steam behaves in many ways like a fluid and will flow down steep gradients and acquire great velocity when the slope and other features of the surface over which it progresses are favorable. The gradients on the slopes of Mont Pelée and La Soufrière, within the zone of destruction in each case, are about 1,000 feet to a mile, and, as seems evident, the finally accepted explanation as to the controlling condition which gave direction to the blasts which swept them will include the principle just stated. In this connection it is instructive to note certain observations made by Messrs. Anderson and Flett, commissioners sent by the Royal Society of London to study the recent eruptions. On the evening of July 9 these gentlemen were on a vessel near Carbet and witnessed an eruption of Mont Pelée.

"As the darkness deepened, a dull red reflection was seen in the trade-wind cloud which covered the mountain summit. This became brighter and brighter and soon we saw red-hot stones projected from the crater, bowling down the mountain slopes and giving off glowing sparks. Suddenly the cloud was brightly illuminated, and the sailors cried, 'The mountain bursts!' In an incredibly short space of time a red-hot avalanche swept down to the sea. We could not see the summit owing to the intervening veil of cloud; but the fissure and the lower parts of the mountain were clear, and the glowing cataract poured over them right down to the shore of the bay. It was dull red, with a billowy surface, reminding one of a snow avalanche. In it there were large stones, which stood out as streaks of bright red, tumbling down and emitting showers of sparks. In a few minutes it was over. A low, angry growl had burst from the mountain when this avalanche was launched from the crater."

The time occupied by the avalanche to reach the sea was "possibly a couple of minutes. It could not have been much more." * * *

"There is no doubt that the eruption we witnessed was a counterpart of that which destroyed St. Pierre. * * * The most peculiar feature of these eruptions is the avalanche of incandescent sand and the great black cloud which accompanies it. The preliminary stages of the eruption, which may occupy a few days or only a few hours, consist of outbursts of steam, fine dust and stones, and the discharge of the crater lakes or torrents of water or mud. In them there is nothing unusual, but as soon as the throat of the crater is reached, a mass of incandescent lava rises and rolls over the lip of the crater in the



MOUTH OF WALLIBOU RIVER AND THE DEVASTATED SLOPES OF LA SOUFRIÈRE, ST. VINCENT, MAY 24, 1902.

"Not a spray or leaf remained in all the stern oppressive landscape to suggest the lovliness that had so suddenly been blotted out." Photograph by Israel C. Russell.



A RIVER OF MUD POURING FROM LA SOUFRIÈRE.

The valley of Wallibou River, St. Vincent, filled to a depth of about 60 feet with hot débris, ejected from La Soufrière, May 23, 1902. Photograph by Israel C. Russell.

form of an avalanche of red-hot dust. It is a lava blown to pieces by the expansion of the gases it contains. It rushes down the slopes of the hill, carrying with it a terrific blast, which mows down everything in its path. The mixture of dust and gases behaves in many ways like a fluid. The exact chemical composition of these gases remains unsettled. They apparently consist principally of steam and sulphurous acid." * * *

The account just quoted of a typical down-blast from a volcano, seen under favorable conditions by trained observers, is perhaps the best evidence on record from which to judge of the nature of certain phases of several of the recent eruptions. In the instance cited there does not seem to have been a lofty column of dust-charged steam standing above the summit of the mountain which deflected the upward blast from the vertical conduit of the volcano, but, owing to the density of the mixture of steam and dust driven out, it overflowed the lip of the crater and rolled down the mountain side. That is one condition, as previously stated, which may bring about a marked variation in the nature of an eruption, and in fact furnish the chief control of the secondary phenomena—the density with which the steam extruded is charged with solid matter. This condition may obtain control even when the explosive violence is not enough to drive the dust-laden steam to a great height. The degree of comminution would no doubt be another factor influencing the result. The finer the solid material was comminuted, the more fluid-like would be the mixture.

In an eruption like that described above the topography may exert a decided influence. During eruptions of great, but of not the maximum, intensity the deep notch in the southwest portion of the rim of the active crater of Mont Pelée would give direction to the escaping dust-charged steam and determine the course the expanding avalanche would take. In the absence of such a notch, as in the case of La Soufrière, the overflow would be radial. A more intense eruption from Mont Pelée might also be radial, the notch in its rim failing to influence so completely the direction taken by the greater discharge. This is what seems to have occurred during the later eruptions of the volcano, when Morne Rouge and other villages were destroyed; but in addition, the growth of the cone of eruption above the rim of its encircling crater destroyed the influence of the vents, and the later eruption spread in all directions in the same manner as on St. Vincent.

Mud flows.—The valleys on the lower slopes of both Mont Pelée and La Soufrière have, in numerous instances, been filled to a depth of 40 to 60 or more feet with hot dust and stones. The streams have thus been displaced and are striving to regain their right of way, but as yet, owing largely to the washing down of dust, lapilli, etc., from bordering slopes, are making but slow progress with their work. In many instances, in fact, the high-grade rills are bringing to the main drainage channels more débris than the master streams can remove,

and the process of valley filling continues. Water finding its way into these beds of hot débris, as already mentioned, causes steam explosions, sometimes of such energy as to resemble a primary eruption from one of the main or true craters. These eruptions at times hurl large quantities of débris into the stream channels which have been partially cleared, thus producing dams and causing small lakes to form. These water bodies rise until they overflow the accumulation of loose material restraining them, when they are rapidly drained, and floods of water heavily charged with débris occur below where the temporary dams were formed. The mud flows originating in these and other similar ways have been frequent on both Martinique and St. Vincent, and have in several instances been referred to as lava flows.

Erosion.—Much that is highly instructive centers about the manner in which the surface waters are removing the freshly added material from the surfaces of Martinique and St. Vincent. Instead of being a protection to the surface on which it rests, the fresh débris is in many instances of assistance in its more rapid erosion. On steep slopes, and even when the surface is nearly level, the rills formed during the numerous tropical showers quickly cut through the loose surface material and, aided by the angular particles in suspension, corrade the soil or rocks beneath. The rains, as it seems, are heavier than usual, owing to two causes: First, the great amount of water contributed to the atmosphere as steam, and, second, the vast amount of dust blown into the air, each particle of which serves as a center for condensation. The process of fashioning the topography throughout the extensive areas from which all vegetation has been removed is greatly accelerated. This more rapid erosion will, no doubt, continue until the surface is again plant-clothed.

The volcanic eruptions have claimed so much immediate consideration from the several geologists and geographers who have visited the stricken islands that the indirect geographical changes resulting from them have not received the attention they deserve. Not only the pulsating streams of steaming water and their occasional great discharges of hot mud demand detailed study, but the way in which the undermining of banks of loose débris leads to landslides, the development of consequent and subsequent streams, the manner in which streams develop and rapidly pass from youth to old age, etc., deserve to be carefully recorded. The streams are not only eroding, but depositing. Deltas are being formed and additions made to the land. The final resting places of the fresh débris which fell on the islands will be in the adjacent sea, where great quantities of fragmental volcanic material is being spread out to form stratified tuffs.

Waves in the sea.—Reports have appeared in the newspapers, from time to time since early in May, of so-called tidal waves. As is well known, the waves referred to have no connection with the tides,

but are similar to those occasionally accompanying earthquakes. So far as can be judged, however, the unusual waves that have recently broken on the shores of Martinique and St. Vincent have not been due to movements in the earth's crust, such as commonly produce earthquakes, although some of them may have been of that nature. The waves referred to have been caused, in most instances, by the disturbances produced in the water of the sea by the blasts of dust-laden steam that have swept down from the craters of Mont Pelée and La Soufrière. Similar waves have also been generated by the entrance into the sea of stupendous mud flows, or, perhaps more properly, avalanches of rock débris and water, like the one which destroyed the Guerin sugar factory on May 5. Again, landslides have occurred in the loose deposits on the Caribbean shores of both Martinique and St. Vincent, and similar slides, as indicated by the breaking of telegraph cables, have probably taken place on the steep submerged slopes of the mountains whose summits form the islands mentioned. In these several ways waves in the sea appear to have been generated, but in all instances they have been low and but little damage from them has resulted. The earthquake shocks that accompanied the recent eruptions have been comparatively light, and, so far as can be judged, not of such a nature as to cause large waves in the adjacent sea. The earthquake shocks, however, may and probably did bring about the descent of some of the landslides on the margin of the sea and on the steep submerged slopes, and in this way are indirectly accountable for some of the sea waves.

Landslides.—The landslides just referred to occurred principally on the west side of St. Vincent, to the north of Chateaubelair, where strips of nearly flat alluvial land, adjacent to the sea, have disappeared, leaving fresh bluffs of loose débris some 30 or 40 feet high. It has been suggested that this disappearance of land, and in one instance of the site of a village, was due to movement along a fault—that is, the subsidence of the rocks on one side of a deep fracture in the earth's crust—but the evidence does not seem to sustain this hypothesis. The lands that have disappeared, as shown by the escarpments remaining, were composed of unconsolidated débris, deposited for the most part directly by streams as deltas. This loose material, resting on the steeply inclined rocks beneath, was in a position to be easily dislodged by earthquake shocks, by the rush of mud avalanches down the valley, at the mouths of which the deposits had been made, and by the return waves when the sea was disturbed by the volcanic blasts or by mud avalanches. The changes made by subsidence of the land are not great, and, as several observers have stated, may reasonably be accounted for in the manner just referred to.

The breaking of telegraph cables a few miles offshore from St. Pierre at the time the city was destroyed and during subsequent eruptions of Mont Pelée seems best accounted for on the supposition that landslides occurred on the steep submerged slopes, similar to those observed at the margin of the adjacent land.

Electrical displays.—The graphic accounts that have been published of the recent eruption give a better idea of the magnificence of the electrical phenomena accompanying volcanic explosions than was previously attainable. These observations show that an interesting and difficult problem here awaits solution. The most striking phase of what is assumed to have been an electrical display during a primary eruption of Mont Pelée on the evening of May 26 is thus described by George Kennan:

"The feature of the eruption that made the deepest impression upon me was the stellar lightning. The uprush of black smoke, the glow over the crater, and the shower of incandescent stones and cinders were all phenomena that had been observed and described before, but the short, thin streaks of lightning, followed by star-like explosions in the volcanic mantle—not only above the crater, but miles away from it—were entirely new. The distinctive characteristics of this lightning were the shortness of the streak, the comparatively great size and brilliancy of the spark, or light burst, at the end of the streak, and the single booming report that followed. Sometimes three or four great sparks, connected by fiery streaks, would flash together in this way, and at other times the stars would burst so far back in the cloud that the streaks were invisible and there was only a circular irradiation of the vapor. If there was any storm lightning of the ordinary kind in the earlier stages of the eruption, it was so much less noticeable than the stellar lightning that it escaped my observation, and I am quite sure that there was no rolling, reverberating thunder at all until near the close of the display, when reddish lightning bolts began to dart down on the volcano from the developing storm cloud over the crater. Before that time all, or nearly all, of the electric discharges had ended in stellar light bursts, and all of the thunder had been made up of separate and distinct reports, like the thunder of a heavy and rapid cannonade."

Supplementing the above account we are fortunate in having an instructive picture of a night eruption of Mont Pelée, drawn by George Varian (Pl. V), in which the appearance of the so-called stellar lightning is well shown.

In reading Kennan's vivid description with the aid of Varian's equally faithful sketch one can scarcely avoid making the tentative suggestion that the streaks of light and brilliant explosions, apparently resembling the trails and occasional bursting caused by meteoric bodies entering the earth's atmosphere, may have been due to intensely heated solid projectiles blown out of the volcano and entering the oxygen-charged air.

Other phenomena.—A final report on the recent and still continuing eruptions of Mont Pelée and La Soufrière must include the evidence in reference to the sounds generated, the earthquake shocks, the areas on which dust fell and its relation to the direction and force of air currents, gravity waves in the air, influence of dust in the air on sunlight, and, most interesting of all, as well as the most novel, the magnetic waves generated, which were recorded almost instantaneously at practically all the automatically recording magnetic stations of the world.

The study of the earth's interior.—Perhaps the chief lesson taught by the recent volcanic eruptions in the Antilles is the meagerness of our knowledge concerning the interior of the earth. In this more pointedly perhaps than in related fields is the saying true that "the known is but a small fraction of the unknown." In the study of the earth's interior, the search for the ultimate causes of volcanic eruptions, etc., a visit to an active volcano is most instructive and suggestive, but such investigations should not end with the cessation of the outbreaks.

The manifestations which reach the earth's surface and on which our judgment as to the condition of its interior must be chiefly based are movements in the rocks, earthquakes, escape of heat, magnetic changes, etc. While several of the phenomena referred to become especially prominent during volcanic eruptions, they are not confined to such occurrences or to the vicinity of volcanic vents, but may be studied at all times and at any locality. Among the records which it is desirable to obtain and from which some judgment in reference to the condition of the earth's interior may be had are the occurrence of earthquakes, their character, direction of motion, location, both geographical and vertical, of their centers and all else concerning them, and changes in the magnetic condition of the earth. Observations in these directions are highly desirable in the vicinity of volcanoes in order that they may serve as danger signals, but may yield valuable returns when carried on at a distance from all centers of volcanic disturbance.

In this connection I wish to suggest that the National Geographic Society can make a substantial addition to our knowledge of the earth by maintaining a magnetic and seismographic observatory. Let a start be made by placing in our Hubbard Memorial Building the best instruments of the nature just referred to that can be had, and extend assistance to individuals, colleges, etc., at as many other localities as practicable, in establishing similar observatories.

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THE PROGRESS OF GEOGRAPHICAL KNOWLEDGE.[a]

By Col. Sir T. H. Holdich, C. B., K. C. I. E., F. R. G. S.

With so large a field as that which is embraced by geography before us, I feel a little doubtful which way to turn in order to gather into one short space both the scattered records of recent geographical history and to present to you at the same time illustrations of some fixed principle which in the course of the development of our geographical knowledge must govern the progress of it. Last year you heard from Dr. Mill a most excellent summary of the present phase of that development in this country. You heard not only of great activity in the wide world of the unexplored and unknown, but of new efforts to train up a fresh generation of explorers; of new schools springing up among us; fresh evidence of the faith that is in us that geographical knowledge points the road to commercial success; happy intimations of the existence of a yet higher faith—the faith which believes that scientific knowledge of the world's physiology is worth the getting for its own sake, whether it paves the way to golden success or not. And now, while recalling the chief geographical events of the year that has passed, while counting the landmarks on the road to a higher geographical education, I would also claim your attention for a brief space to a few technical problems which beset the business aspect of future procedure, and which, so long as we make it our boast that we belong to the biggest empire in the world, ought most certainly to attract our earnest attention.

The unknown world is growing daily smaller. It is, indeed, narrowing its area with a rapidity which is absolutely regrettable. If you think of those delightful days when the men who went "down to the sea in ships" brought gold and ivory to the steps of Solomon's temple, believing that beyond their nautical ken all the rest of the world was but flat emptiness; or even centuries later, when Marco Polo's truthful tales of Asia were discredited as wild fables, or, again, in almost modern times, when Vasco de Gama bent his knees in pious prayer ere starting on the buccaneering venture which was to change

[a] Address to geographical section of British Association for the Advancement of Science. Reprinted from Report of British Association 1902, pp. 662–677.

the destinies of the East, you will find it almost impossible to look at the well turned out maps of to-day, wondering where next it may be possible to strike a new feature or unfold a new vista to geographical enterprise, without something like a sigh. But it is with the world as we find it mapped to-day that we have now to do, searching out the position of such blank spaces as still exist and considering the best means of dealing with the vast area of its half-exploited surface so as to obtain the best results for the time and labor spent on completing our knowledge of it.

ANTARCTIC PROSPECTS.

To the polar regions we naturally turn first, for they form the special domain of modern initial exploration. We are very far yet from having elucidated the great geographical problems of sea and land distribution which lie hidden under the depths of paleocrystal ice. We only know, indeed, from inference that at one end of the world there exists an unmapped sea and at the other an unmapped continent, round the edges of which we are even now feeling our way. When the *Discovery* left the New Zealand port of Chalmers on December 24 last for the South Polar regions, this was the quest which, in the modest language of her originator, Sir Clements Markham, lay before her: "To determine as far as possible the nature and extent of the South Polar lands" and to "conduct a magnetic survey." If we look at the unexplored area of these South Polar lands as a whole and examine the plan of international geographical campaign which has now been directed against them, we shall find, I think, that the present enterprise is by far the most complete and systematic, as it is the most scientific, that has yet been undertaken in the far south. It is impossible but that great results should be attained from so complete an investment of the unknown continent.

With the *Discovery's* investigations, which will be directed to Victoria Land—the land of the historic volcanoes Erebus and Terror—from the side of Tasmania and New Zealand, will be associated at least three other expeditions, all aiming at a final solution of the South Pole problem. From South America Otto Nordenskiold's expedition has taken the shortest sea route past the South Shetlands to Grahams Land and has already passed a winter amid the ice. From South America, again, the Scottish expedition under Bruce will work its way past Sandwich Island, skirting the Antarctic Circle, some 50° to the east of Nordenskiold, almost on the Greenwich meridian and as nearly opposite as possible to the *Discovery's* attack from the other side of the pole, while between the two will be the German expedition of the *Gauss*, pushing southward about the meridian of 90° E., a worthy rival in scientific equipment to our own ship, the *Discovery*. And there is no branch of scientific inquiry which will be

advanced by this international attack on the great unknown southern land of more interest than that which pertains to the history of the world's geography. Independently of securing a firmer outline to the vague definition of southern land areas of the present day, it is there that we hope to find evidences of another distribution of those areas in primeval times. Shall we be able to trace the Patagonian formations, those recent basaltic lavas which overlie trees, beyond that point in Grahams Land where we know that they occur again, to the Australian side of the Southern Pole? Shall we find that Erebus and Terror are but the natural extension of that magnificent array of volcanic cones which overlook the Pacific from the Patagonian Andes? Will the Miolania, the great turtle of Patagonia, not unknown in Australia, complete with his bones another link in that chain of many evidences that Patagonia and Australia once met across the extreme south? You may say this is not geography. I hardly know whether in these days it is still necessary to plead that between geography and natural sciences, whether of geology, biology, or anthropology, the connection is so intimate that in the actual field of research it is impossible to disconnect them. Modern geography is but a development, and while the process of its evolution is perhaps to be found in strictly geological fields, it has so modified and influenced the problems of life and the distribution of it throughout the world that a collector of facts like myself finds it convenient to accept, for the mere sake of simplicity, the science of geography as the best basis for divergent inquiries into many other scientific fields, which can be differentiated at leisure by the natural philosopher.

NECESSITY FOR STUDY OF GEOGRAPHICAL HISTORY.

But while we are justified in expecting much from this great international movement, we must still moderate our expectations. We must admit that in the field of purely naval exploration we have not the same developments in mechanical and instrumental accessories which place within our reach the possibility of conducting land expeditions on far more scientific and exact methods than were possible to our grandfathers. Wireless telegraphy, for instance, will not yet enable a ship fast bound in arctic ice to determine her longitude, and the restless ocean still precludes the use of many of the more finely graduated instruments which are essential to the exact measurements pertaining to triangulation. Methods and instruments, indeed, will not differ materially from those adopted by Franklin or by Ross more than half a century ago. Better instruments of their class no doubt are within reach, owing to the extraordinary accuracy of modern production; but better hands to hold them it would be impossible to find. We are often so pleased with ourselves in these days that we are apt to forget what has been done by our geographical forerunners in the

same field as ourselves. I have but lately returned from a journey full of geographical interest which has carried me over some of the tracks left many years ago by a British scientific expedition to the South Seas, which will be ever associated in the memory of all geographers with the names of Charles Darwin, and H. M. S. *Beagle*. With the wider scope for gathering information which is afforded in these days by the growth of civilization and the shooting out of its long tendrils into the waste places of Patagonia, it has been possible to verify some of the suggestions as to the structure and geographical configuration of that southern continent which were offered by the observations of Darwin, and to examine here and there, in some detail, the results of recent local surveys in testing the accuracy of the coast outline and of the coast soundings established by the *Beagle*. Of the former I can only say that they seem to me prophetic; of the latter, so little change has taken place in South American coast configuration during the last fifty years that practically the charts of the *Beagle* are the charts of the Chilian and Argentine admiralties of to-day, with hardly a noticeable variation. Such magnificent results as were achieved then are hard to beat at any time. We do not hope to beat them. We can only hope to imitate them. They stand good for all time, and it is useful to recall them now and then in order to emphasize a truism which is occasionally overlooked by modern geographical explorers. It is not the most recent work in the field of exploration which is necessarily the most valuable. One of the great sins of omission in modern exploration is that of a failure to appreciate the efforts of preceding geographers in the same field of research as ourselves—the want of a patient absorption of all available previous knowledge before we attempt to add to the sum of it. We are not all of us gifted with the patient determination of that great traveler Sven Hedin, who spent three years in reading about central Asia before he wrote a word on the subject. It can not be too strongly urged in these days of narrowing fields for activity that although geographical research is essentially an active function of an active life it demands yet more and more, as time goes on, the application of the scholar added to the determined energy of the explorer.

FORMATION OF A CENTRAL COMMITTEE OF GEOGRAPHICAL ADVISERS.

It is in this connection that I would advance a suggestion which I have already heard discussed by travelers anxious to apply their energies in well-directed efforts toward the acquisition of really useful scientific information. It concerns the possibility of establishing a central geographical committee which should gather together expert knowledge in all branches of natural science, and be prepared to give technical advice to travelers and explorers, not only as to the literary sources from which the best information may be derived, but also to

furnish hints as to the best localities for research in any special branch of science. This would certainly shorten the preliminary labor of collecting information; and in many cases when expeditions are planned at short notice it would be invaluable in indicating opportunities for special research which would otherwise be overlooked. It is so much more frequently want of time, rather than want of inclination, which prevents the acquisition of that preliminary and most essential knowledge which alone can rightly direct the effort to the opportunity and fit the two together, that I have much sympathy with the pathetic appeal of more than one young explorer who has complained that it is necessary to travel all around London in order to find the man (to say nothing of the book) who will tell you in concise language exactly what to look for in the land which you are visiting.

CONTRACTION OF THE WORLD'S "TERRA INCOGNITA."

It is, however, when we leave the high seas with their almost inexhaustible store of unexplored ocean floors and icebound coast line, and turn from oceanography to the more familiar aspects of land geography that we find those spaces within which "pioneer" exploration can be usefully carried to be so rapidly contracting year by year as to force upon our attention the necessity for adapting our methods for a progressive system of world-wide map making, not only to the requirements of abstract science, but to the utilitarian demands of commercial and political enterprise.

ASIA.

Take Asia, for example. Nearly half of the great continent pertains to Siberia, and within the limits of Russian territory the admirable organization of her own system of geographical exploration leaves no room for outsiders to assist usefully, even if political objections did not exist. In central and southern Arabia there is undoubtedly still much to learn, but of the remaining countries which intervene between the Mediterranean and India, of Persia, Afghanistan, and Baluchistan, it can only be said that the work of the geographical pioneer has already ended where that of the engineer and surveyor has commenced. In the Farthest East again—in Manchuria, China, Tonkin, and Siam—there is much more room for the practical exploration of the road and railway maker than there is for the irresponsible career of the geographical traveler. The highway from China to India is almost as well known as that from London to India, and the activity of railway enterprise in the south of Asia bids fair to rival the triumphs of Siberia. It is only in the central deserts of Mongolia and the wastes of Tibet spreading southward to the Himalayas that we can find untrodden areas of any great magnitude, and even in central Asia before venturing on a statement of future possibilities in the field of exploration, it would

be well to wait for the records of that most intrepid traveler, Sven Hedin, who promises us material of scientific and historical interest as the result of his last three years' travel far in excess of the monumental contributions which he has already made public. Historically the interest of the world of inquiry in Asia where we find the origin of the great races of the world and the birthplace of all religions must always be immense; but that history can only be elucidated by a clear illustration of the great highways of the continent which were open to the vast migratory movements of mankind in prehistoric periods. We do not in the least understand the condition of climate, nor are we quite certain even of the relative distribution of land and water in high Asia in the days when its swarming population first began to flow south and west, carrying the elements of a language which we have been accustomed to regard as primeval into the swamps and plains which lay beyond the Himalayas or the Caspian. It is only through geographical research that some dim outline of those early stories can be realized; and although the researches of Stein and the marvelous discoveries of Sven Hedin around the ancient lake district of Lob Nor will, after all, only throw the world's history back for a few centuries, it is by means of these first steps backward that we can feel our way to an appreciation of the earlier processes of this phase of human evolution. Nor in the interests of utilitarian commercial speculation is geographical research in Asia yet to be set aside. We indeed know comparatively nothing of its resources in mineral wealth. It is quite within the bounds of possibility that one of the great central treasure houses of nature lie enveloped in the geological axis of the highest mountains of the world, and that we may yet be enabled to explain why every river which flows from Tibet washes down gold in its bed. But this will only be when the Tibetan Lama is prepared to shake hands with the Uitlander; and I fear that recent South African history will not encourage the embrace. Meanwhile there is no more promising field still open to the bona fide explorer than that of Tibet and the farthest ranges of the Himalayas. Few people are aware how vast an extent of the Himalayan area still remains untrodden by any European. This is due to no want of enterprise on the part of our Indian surveyors and political officials. It is due partly to physical inaccessibility and partly to that intense (and easily understood) objection to the interference of the stranger in which many of our transfrontier neighbors permit themselves to indulge. Nevertheless would I commend to those who still desire to walk in the rough and thorny path of pioneer geographical discovery a similar enterprise to that of our aforetime secretary, Mr. Douglas Freshfield, who lately succeeded in passing beyond the bounds of official exploration into the eastern Himalayas. We have had many travelers in the Himalayas, but they have not always distinguished between the fascinating pleasures of romantic adventure and the earnest pursuit of geographical business.

STUDY OF GLACIERS.

To Mr. Freshfield we certainly owe an introduction to a new vista of great scientific interest in the study of the formation and movements of glaciers. Here perhaps, we are treading gently on the skirts of geological science; but I have never yet found that part of the world where the careful study of local geographical conformation will not inevitably invoke an inquiry into geological construction. We must accept the inevitable criticism and go on with our glaciers. Where in the world can there be such an area for research into the conditions of glacial formations as is presented by the Himalayas? I grant the physical and political difficulties in the way to which I have referred, but still well within the limits of our own red border there are glaciers yet to be studied, which, if not the largest, are yet large enough to satisfy the loftiest aspirations, and beyond that border the difficulties of approach are lessening day by day and are no longer so formidable that they need hinder the steps of any determined explorer.

SOUTH AMERICAN GLACIERS.

The speculative interest in glacial movements and their influence on the geographical conformation become far greater when one moves in a country which has been recently shaped and polished, grooved, and fashioned by glacial action; when huge blocks of granite or porphyry, standing sentinel over terraces and ancient glacier beds, witness to the passing of icebergs in prehistoric seas. Such conditions one may find in two widely separated areas, viz, in the Pamirs and in Patagonia. What causes led to the formation of the first vast ice cap of which the glacier is the latest evidence; what caused its disappearance, its reappearance; why are the glaciers again withdrawing from the mountains, and what causes the universal process of modern desiccation, of which there is such ample evidence in the Pamirs, in Baluchistan, in Patagonia? It is to the Himalayas that we turn first for an answer to this question, but there are other fields almost equally promising, and one of them is to be found in South America. No one now can pretend any longer that we know nothing of Patagonia. Probably no country in the world has been described by so many geographers in so many different ways; there, at any rate, is a land of glaciers and snow fields awaiting research which presents few of the physical difficulties of the Himalayas. Here is a wonderful country truly, where glaciers reach down to the sea in low latitudes, casting little icebergs into waters fringed by green banks of fuchsia and myrtle, and of bamboo, where the laurel grows into magnificent timber, competing with the Patagonian beech for roothold on the moss-covered soil. The round gray heads of the granite hills, scratched and seamed by a discarded ice cap on one side of the narrow straits balance the snow-bound peaks of the

Cordilleras on the other. No physical difficulties bar the way to the investigation of glacial phenomena amidst some of the most striking coast scenery in the world. Near the parallel of 51° south are two Patagonian lakes closely associated—Argentina and Viedma—which offer opportunities for the study of glaciers such as are probably not to be found anywhere else in the same latitude. For here the phenomenon of disappearance is in the stage of natural illustration. Glaciers are disappearing rapidly which but a few years ago seemed to be a permanent feature of the surrounding mountains, and the lake surface is checkered with their débris. There, too, may be studied for hundreds of miles northward the natural sequences of their disappearance—the formation of fresh-water lakes and their gradual desiccation in turn—whilst all around there is the continued story of geographical evolution due to the alternate forces of glacial and volcanic action written in gigantic characters on the face of nature.

CENTRAL SOUTH AMERICA.

Not very much has been added of late years to our practical knowledge of the hidden depths of central South America except from the inexhaustible mine of information possessed by that eminent geographer, Colonel Church. A Brazilian expedition in 1890, the explorations of a commission sent to investigate the interior with a view to the establishment of new political capital to Brazil in 1892–93, the discoveries of Dr. Ramon Paz in 1894, and a checkered journey in the valley of the Orinoco by Stanley Paterson in 1897, form the principal records of modern days. There is doubtless much which is of the greatest commercial and political interest still to unravel in connection with the geography of the great river basins of the continent. But in South America we are threatened with perhaps the greatest development of what I may call artificial geography that the world has ever seen. Not only will the consummation of the Panama Canal project change the whole system of our Western sea communications and probably exercise a more enduring effect on the world's commerce than even the Suez connection between East and West, but the possibilities of linking up by a central canal system the three great river basins of the South—that of the Orinoco, the Amazon, and the Plata—is under serious consideration, and the mere project will in itself lead to an exhaustive examination of much untraveled country. Thus, even South America no longer offers a large field for the geographical pioneer of the future. With its narrowing areas of terra incognita and its almost phenomenal advance toward a leading position as the pastoral and meat-producing quarter of the habitable globe, with possibilities of development in this particular line probably exceeding those of Australia, New Zealand, and South Africa all put together, it is surely high time that South America turned her attention toward a combined and sustained international effort to place her scattered and

most insufficient geographical surveys on a sound geodetic basis extending through the whole continent.

NORTH AMERICA.

In the geographical fields presented by North America, as also by Australia, magnificent as are the opportunities for acquiring that personal acquaintance with the great depositions of nature which environ new conditions of life, and shape the course of human existence to its appointed ends; or, in other words, to acquire a geographical education from original sources of instruction, there is but little opening for the enterprise of the pioneer who aspires to show the way into new fields. There is no lack of native enterprise in colonies peopled by the stout-hearted descendants of generations of explorers. Neither Canadians nor Australians wait for England to show them how to develop the resources of their own country or pilot the road to new ventures. On the contrary, we have to turn to Canada now for instruction in the higher art of geographical map making and to admit that England has been left far behind in the development of the special branch of science which deals with the illustration of the main features of geographical configuration in relation to their geological construction.

AFRICA.

In Africa the advance of our knowledge of the main outline of the geographical features of the continent has been so rapid since the days when the Nile was first traced to its source by Speke that a perfect network of explorers' lines of travel now embraces the continent in its meshes, and it is only in the intermediate spaces that room for enterprise on the part of the poineer is left, even if it may not be said altogether to have vanished. A reference to the little map published by Mr. Ravenstein in the Royal Geographical Society Journal for last December will show you at once that the hydrography of Africa has been fairly well traced out in all its main arteries, leaving but few unexplored spaces of any great extent, and that such spaces, where they occur within the area which is especially open to Englishmen, demand an organized system of exploration more complete in its results, more carefully balanced in its relation to the geographical illustration of those lands which are beginning to form centers of civilization than can be secured by the process of poineer route making. In short, we want a system of geographical surveying allied to those systems which have been perfected after years of careful experiment by Canada, or Russia, or France, or by England in India. This, however, brings us into a field of technical inquiry of great importance, into which, so far as it deals with geography—i. e., with the measurement of the earth's surface and the illustration of its configuration by means of maps, I propose to enter briefly in this address.

MODERN REQUIREMENTS IN GEOGRAPHICAL MAP MAKING.

You will agree with me that geography in the abstract, without illustration—the geography which used to be taught by geography books without maps—is but a poor and inefficient branch of academic knowledge, hardly worthy even of an infant school. It does not matter what branch of this comprehensive science you approach, whether it is historical, or physical, or political, modern or ancient, the only substantial presentment of the subject to man's understanding is that which has recourse to map illustration. Words (especially words bearing such indefinite applications as our modern geographical terminology) can never convey to the imagination the same substantial illustration as maps convey to the eye. You may think that all this is mere truism; so it may be; but I assure you that what I may call descriptive geography—that is to say, geography without the aid of maps, has more than once nearly precipitated national disaster in quite modern times—disaster quite as perilous as any which in military fields has been caused by blank, wholesale ignorance of the features of a country in which strategic movements are undertaken. There comes a time in the history of every developing country when the increase of its people, and the consequent distribution of land, demands surveys for the purposes of fiscal administration. Consequently such surveys are common everywhere; and from these have been built up, piece by piece, like a child's puzzle, the geographical maps of many half-occupied lands, illustrating only such portions as are adaptable to economic development, and leaving blank all that promised to be unproductive and unprofitable.

FIELD OF GEODESY.

It was only when it was discovered that the sum total of such a production was apt to cause great confusion in land assessment, inasmuch as it often did not equal the actual area of the land distributed, that there arose a school of mathematicians who concerned themselves with determining the dimensions and figure of the earth, and founded that apparently complicated system of primary map making which now takes count of such matters as the curvature of the earth's surface, the convergency of meridians, and other spheroidal problems which affect the construction of the map. Thus arose "geodesy," and geodesy has numbered among its apostles many of the greatest mathematicians of the age. Geodesy, the science which deals with exact measurements, was never an embodiment of abstract mathematical investigation. It had always a utilitarian side to it, and it is unfortunate that this view of the science has been occasionally lost sight of in late years. For we have not done with geodetic investigation yet. Magnificent as are the results obtained by the mathematicians of the past, there are

still further refinements to be introduced into those factors which we daily use for the reduction of our terrestial observations ere we obtain perfect mathematical exactness (if we ever attain it) in our results; and we still must look to the processes of geodesy to give us that backbone, that main axis of indisputable values from which our network of triangulations may spread during the first steps in geographical map making. To a certain extent geodesy is the support of technical geography, and a short inquiry into its present conditions of existence may not be out of place.

It is to North America that we must now turn for instruction in the latest development of the science, and to South Africa that we must look for its future application. Russia has not lost sight of the necessity imposed on her for an extension of her magnificent Europeon geodetic system through the vast breadth of her Asiatic possessions, but we ourselves in India are concerned nowadays rather with scientific observations on collateral lines, and with the collating and perfecting of the results attained by the great achievements of past years, than with any developments in fresh fields of geodetic triangulation. Germany and France, ever alert where colonial interests are concerned, are busy in Africa, but I am not prepared to say how far their geographical efforts are based on the strict principles of geodesy.

In North America, along the meridian of 98° through Texas, Kansas, and Nebraska, geodetic triangulation still forms one of the most prominent schemes of modern work undertaken by the Coast and Geodetic Survey, and in South Africa there is growing northward into the Transvaal slowly, but we hope surely, the framework of a gigantic arc which one day will be extended by Sir David Gill from the Cape to Cairo.

I am anxious to impress on you that the science of geodesy is not a science of the past. It is still active, and with all its refinements of minute accuracy and exact precision in observation and in calculation it should be the initial mainstay, and it must be the final court of appeal, as it were, for all those less rigorously conducted surveys of the reconnaissance and exploration class which we term geographical.

But this accurate framework, this rigorously exact line of precise values which ultimately becomes the backbone of an otherwise invertebrate survey anatomy, is painfully slow in its progress, and it is usually haunted by the bogey of finance. It does not appeal to the imagination like an Antarctic expedition, although it may lead to far more solid results, and it generally has to sue in forma pauperis to government for its support.

GEOGRAPHICAL SURVEYS.

And thus it happens that long before the tedious and expensive processes which are involved in the term geodetic triangulation can possibly be carried to an effective end the cry goes up for a geographical survey. It is wanted by the administrator to whom it is all important that he should know the roads and river communications, and the productive areas of the land he has to administer, and be able to locate the various tribal sections or peoples with whom he has to deal. In the political department a geographical map may be said to be absolutely necessary for the political purpose of defining limits and boundaries. It has been, I am aware, occasionally dispensed with, but never with satisfactory results. To the officer on whom rests the responsibility of preserving peace and good order it is most desirable that the military features should be fairly represented in such a manner that at least a general plan of action can be arranged at short notice. For the economic development of the country it can not be too strongly urged that a general geographical outline of its surface is indispensable to the selection of lines for special technical examination, whether for roads, railways, canals, or telegraphs. How often lately in the history of our colonial or frontier progress have vast sums been expended on special lines of railway in ignorance of the fact that better alignments of infinitely less physical difficulty would have been at once revealed by a general geographical map even on the smallest scale! In short, the cheapest, the quickest, the surest, indeed the only satisfactory method of regulating the progression of public works, the development of commerce, the proper recognition of the frontier boundaries, the administration of justice, and the military control of a large and growing colony, or of a long stretch of military frontier, is to be armed with a perfect summary of what that country contains in the shape of a geographical map; and yet it is only quite lately that this fact has been recognized by English administrators and English generals in their dealings with new colonies and new frontiers. Russia learned the lesson a generation ago at least. When she reached out a hand for Constantinople her army was accompanied across the Balkans by whole companies of surveyors, who worked on no sketchy system of indicating lines of route here and there. They pushed at least seven series of triangulation across the mountains, and on that as a basis they mapped the whole country in detail on a good military scale (about an inch per mile) right up to the very gates of the Turkish capital. For years her brigade of topographers has been busy along her Afghan and Siberian frontiers. In Persia, Baluchistan, the Pamirs, and China, wherever in fact there may be in the future some prospective view of a closer political, commercial, or military interest than exists at present, there they are to be found. France has always been strong in the geographical field, and the late achievements of

Frenchmen in the world of exploration and of exploratory map-making are only equaled by the scientific knowledge and literary ability displayed in their technical literature on the subject. Colonel Laussedat's contribution to the History of Topography is to be reckoned with as a standard work. In Canada and North America we have perhaps a practical exposition of the art of geographical surveying which is as unequaled in completeness and comprehensiveness as the country with which it has to deal is unequaled as a subject for its application. There the close association between geological structure and geographical conformation is so fully recognized that the same technical process of surveying is applied for the purpose of the double illustration. The Canadian geological survey is their geographical survey, and I think that it is to Canada (if not to India) that we owe the first recognition of the fact that geographical surveying is a separate, distinct, and most important branch of the general art, which should form the basis the mother survey as it were— from which all other surveys should spring. In India I am happy to think that this advance in the science of geography is now well understood. It has been more or less forced on us by the necessity for such rapid and comprehensive surveys as are required for frontier military operations, for the purposes of boundary demarcation, and for the important duty of keeping our own transfrontier information up to the level of that of our neighbors. In our African colonies it has, alas, been discovered a little too late that geographical surveys are a sound preliminary to military operations; but the discovery once made it is not likely to be overlooked. Here, indeed, was presented a most forcible illustration of the danger of building up a geographical puzzle map; of piling one on to another the results of local fiscal surveys in the hope that when they were all put together they might make a good topographical guide to the country. Needless to say the result was disastrous from the scientific point of view, and it might almost be said of it that it was disastrous from the military point of view as well. Imagine for an instant that the Canadian system of a geological survey (involving of course accurate topography) had been applied ab initio to South Africa, who can possibly say what the result might not have been by this time? The expansion of the Randt mines, for example, depends at present on local experiment carried out no doubt by most able engineers with all the knowledge of scientific mining that is to be acquired in these days of advanced specialism. But all the same I may be permitted to suggest that their experimental ventures, their tentative borings, are subject to a good deal that is almost guesswork for their application, and that a comprehensive, carefully conducted geological survey of the whole country would probably have afforded valuable indications in many unexpected directions. So also as regards schemes for local irrigation. Take the northwestern part of Cape Colony, for

instance, the district known as the Karoo, where the best military map existing at the time of the war did not even pretend to show the main roads through the country. The stage of development at which that part of the colony has arrived in the all-important matter of local irrigation is only worthy of the Dark Ages. It would be laughed at in Persia or Afghanistan. The Arabs of mediæval times were experts in the art of the conservancy and distribution of water in dry lands compared to the modern South African (or South American) farmer. Now, I do not say that schemes for merely local irrigation require geographical maps to support them. Such schemes only require a little enterprise, a little common sense, and a little capital, but I do say that the geographical map would long ago have revealed the opportunity for comprehensive schemes, such as exist in India, just as it would have pointed out the best alignment for roads and railways, the best means for dealing with an enemy who can move 50 miles in a night, and who can make, not merely a few square miles, but a whole district the theater of his operations. What was wanted (and is still wanted) in South Africa is what is wanted in every part of the continent subject to British suzerainty. I know that I am but echoing the urgent demand which has been made by every commissioner and governor within the limits of that vast area—not for elaborate or special maps for fiscal and revenue purposes, all of which will come in due time—but for scientific geography which shall now take the place of the preliminary work of pioneer explorers, and deal with the country as a whole instead of tracing it in outlines and in disjointed parts. In short, they require all gaps filled up. They want to know what the country contains in the way of forests, of open land suitable for agriculture, of desert and swamp, of opportunities for roads and railways, for telegraphs and irrigation, before deciding on the right portion for the center of an arterial system of public works which shall pervade in natural and orderly sequence, and in due time, every part of the body of the country of their administration. Now, this is scientific geography. It is not ordnance map making nor anything very much like it. It is a comparatively new demand on the scientific resources of England, and those resources are by no means equal to the demand. Before considering resources, however, we must look to the scientific means to this geographical end. I have already referred briefly to the subject of geodesy, and I have told you that what is termed geodetic triangulation is a function of high scientific order, demanding not only minute and painstaking care on the part of an able staff of observers, but very considerable time and very considerable expense to carry it to a satisfactory issue. I have also pointed out that inasmuch as the exact distribution into parts of any large space of the world's area must ultimately depend on the exact measurements which are a function of only the highest class of geodetic triangulation, we must look

finally to geodesy to support the framework of our geography and to give it its rightful place in the great total of the world's mapping. But the demand for geographical mapping is not satisfied with the promise of an elaborate basis for the work which has first to be constructed with the expenditure of much time and money before anything in the nature of a final map can be produced for purposes of administration. The political world, too, can not always sit patiently through all the international disagreements, the losses, the unrest, and the positive national danger to which an unsettled boundary gives rise, while the geodesist works slowly through the country year after year, piling up sheaves of equations and folios of observations, but never a square mile of practical topography. As for the military department I hardly know what to say. There is the example before us of Germans, Russians, French, and Americans, all conducting their campaigns with maps in their hands, taking every special means at their command in order to acquire such maps before they commence operations; while the Boers have fought us to the bitter end with a practical knowledge of the country which is even better than maps, and which is exactly that class of knowledge which maps are supposed to replace or supplement. None of them wait for geodesy.

Certainly the attitude of the military department is not one of neutrality. They would like the maps, they are even anxious to get them, but they are not quite certain that they are worth paying for. However that may be, I can only express my own conviction that geographical mapping will be found to be an urgent necessity in every corner of the unmapped world subject to British influence. We would like to wait for those accurate determinations of geodesy which would at once furnish us with the best of all possible means for commencing a comprehensive geographical survey. But we can not afford to wait, and the great geographical problem of the age is how to reverse the natural sequence of scientific procedure and to obtain maps of the unmapped world which no subsequent geodetic operations shall condemn as inaccurate. It is not a question of expediency; it has been one of necessity for many years past; and inasmuch as necessity is the mother of invention, I think that it will finally be conceded that means have been found for insuring sufficient accuracy in geographical work to render it capable of enduring the subsequent tests of completed geodetic measurement without dislocation and without interference with the general utility of the maps, even if that accuracy be not scientifically perfect.

It is not my intention to bore you with technical details. I only wish to impress upon you that in the field of scientific geography, as in other fields, "the old order changeth." We must work on new principles in order to meet new demands.

USE OF THE TELEGRAPH IN GEOGRAPHY.

One of the chief means to this end is the telegraph. Few people appreciate the important rôle which is played by the telegraph in these days in the field of geography. It was not so very long ago that the first step toward regenerating a natural wilderness, or for securing access to new commercial openings or centers of uncivilized population was held to be the construction of roads and railways. Means of physical access was the first step toward the development of a country which was regarded as unenlightened from the standpoint of European civilization. It is so no longer, for the telegraph often threads its way through many a dreary waste of unpeopled earth, uncoiling its length for hundreds of miles in advance of any railway, or indeed of any road, which can in the ordinary sense of the term be described as a constructed road. I will give you an illustration. On the Patagonian pampas not so very long ago, in the midst of a wide wilderness of snow, after losing our way in a blinding snowstorm and camping on our tracks for the night, we struck the end of the telegraph line which is now being pushed across Patagonia, and which will eventually connect the Atlantic with the Pacific. We had seen no roads whatever for a great part of the distance we had traversed. Our daily procedure was the simple process of following a guide over the illimitable stretches of bush-covered uplands which reach down from the eastern foot of the Andes in gentle grades to the Atlantic shore; and when we did at last fall in with the great central line of transcontinental communication we found it to consist of the wheel marks of certain previous wagons which had drifted along that way—a sort of road which it was exceedingly easy to lose in the fading light of a stormy winter's day. On this road there was nothing but a telegraph end and the tents of a few telegraph officials, and we were some 150 miles from our destination on the Atlantic coast. And so it happened that after weeks of absence from any means of communication with the outside world we were thus suddenly put in possession of its very latest news, and the very first message that passed from the end of that line into my hands was the message of peace with South Africa, signed an hour or two previously. I accepted that message as a happy omen for the result of our Patagonian mission. And thenceforward (thanks to the courtesy of the telegraph chief at Buenos Ayres) nightly as we sat in the snow we read all that was important from the London evening papers of that selfsame day. We were not starving by any means, but had we wanted a loaf of bread in that unbroken stretch of snow covered bush land we certainly could not have got it, while here was information flowing in with a daily ease and regularity that I greatly missed when once again I was within reach of clubs and civilization. The importance of telegraphs

in the field of geography, however, is not confined to the transfer of news to casual travelers. It is the facility which it places in the hands of the geographer for determining his position in longitude that renders it so important a factor in the prosecution of a geographical survey. Everyone knows that the first duty of a geographer is to discover his latitude and his longitude. Hitherto the determination of the first has been a matter of no great uncertainty, but as regards the latter one can only say that the confidence expressed by most explorers in the results of their observations has never been justified by the final verdict of a subsequent determination. It is, in truth, most difficult even for the most practiced observer to obtain an absolute value in longitude on which he can rely within such limits of accuracy as are essential to the construction of a map where these values have to be employed differentially. The telegraph places in our hands the means of differential determinations within a degree of exactness that surpasses even that of the most careful determination of latitude; and the telegraph is everywhere. Supplementary to the facilities of time signaling by telegraph is the wonderful accuracy of graduation introduced into the smaller classes of new instruments which in these days replace the cumbersome equipment of the past. With a small 6-inch theodolite fitted with a complete vertical circle, time values can be determined within a fraction of a second and latitude values to within two seconds of arc, always provided that that great bugbear of the astronomical geographer, level deflection, does not interfere with his results. But the same minute accuracy in graduation which has so improved the ordinary little instruments which you find in the hands of the professional geographer has, when combined with new methods for accurate linear measurement, also placed it in his power to carry out a fairly coherent and systematic triangulation with great rapidity and accuracy over large areas of country whenever the configuration and characteristics of that country are favorable. Usually they are favorable. Large expanses of flat desert, of undulating veldt, or of unbroken forest are the exception, not the rule, and they must of course be dealt with as their special peculiarities demand; and for the normal conditions of land configuration, given that the explorer is specially careful about his base measurements and his initial data, he can certainly, with modern instruments and the facilities for check given him by the telegraph, carry on a rapid and comprehensive geographical survey which will fulfill all the conditions required by the administrator, economist, political geographer, or military commander within such limits of accuracy as will insure its standing all the subsequent tests that geodesy may apply without any apparent map dislocation. And practically that is all that is wanted for a first map. I have used the word "rapidly." Few people, even scientific geographers, have really

grasped the full meaning of the term as applied to surveys on geographical scales (i. e., 1:250000, or about 4 inches per mile, or less) under normal conditions. Such surveys can be completed quite as fast as an army can advance in the field, even granting that the advance is continuous. They can even to a certain extent precede that advance in face of an enemy. A single triangulator with a staff of two or three topographers in a fairly favorable country will be responsible for an out turn which may be counted by hundreds of square miles per day. The records of both American and Canadian surveys will prove that the marvelous progress made in the frontier reconnoissance surveys of India is nothing abnormal or unexpected.

NECESSITY FOR TRAINING SCHOOLS.

So far I have spoken about the system only, a system which has been nearly perfected by experiments in Canada, Russia, India, and elsewhere. Now we have to turn from the work to the workmen. It is only lately, quite lately, that England has discovered that such workmen are wanted at all. Five or six years ago there was not a topographer nor a topographical school in England. But the demand during late years has been insistent and constant, with the result, I am glad to say, that efforts have been made in various directions to start topographical schools, and a distinct change is apparent in our methods of instruction at military headquarters. No purely technical central civil schools, such as exist on the Continent, are to be found in England, and the natural result is that at present England possesses no finished topographers and not many men who know what is meant by a geographical survey. In the wilds of Patagonia (which is, I must premise, a country beset with special climatic difficulties but not otherwise one unsuitable to the topographer's art) I met many men of great intelligence and exceptional skill who had been gathered from various quarters for the purpose of topography. There were Italians, Argentines, Germans, French, and Swiss, but not an Englishman among them. Russians of the type of my old and unforgotten friend Benderski have long been famous for their skill; but, although English administrators and soldiers are alike crying out for more and better assistance in the active field of topography, they can not get it from England. The establishment of a school of practical geography, such as must eventually guarantee the existence of a military topographical corps, would be a matter of congratulation deserving to be noted as an important step in the advance of the geographical education of the country, no less than the school at Oxford which deals more directly with civil interests and is rightly most concerned with the academic aspects of geographical instruction. Even this, however, is hardly sufficient. I am convinced that the recommendation which arose from certain resolutions found in the geographical section of the

British association meeting at Bradford two years ago in favor of the employment of natives in Africa for African work, just as Indian natives are employed in India, is thoroughly sound. We want schools in Africa as well as in England. Only in this way will the vast areas still unmapped in our African protectorates be dealt with at reasonable cost and in a reasonable space of time.

PHOTOTOPOGRAPHY.

Certain developments in the practical field of geography have lately been brought to the test of continued experimental application, and the progress of these experiments deserves a passing record. Notably the application of photography to purposes of geographical illustration has received immense impetus from the apparent facility with which the experimental media can be handled. In favor of the haphazard landscape illustrations, with which we are usually deluged by travelers, there is little to be said. They are far more frequently illustrations of the personal progress of the author than of the general character of the country he progressed through. Neither is there much more to commend in photographs designed to reproduce geological or tectonic features, glacial configuration, special orographical conditions, or the like, unless the position of them and the direction of the line of sight from the point of view are very clearly indicated on a corresponding map. At the best they are apt to be deceptive for the reason that they can but deal with one side of a subject and with only a partial view of the particular feature they represent. Everyone knows that an apparent range, or even a system of ranges, of mountains may be nothing but the revetment of a high plateau or table-land, but the photograph of such a mountain system will give no indication of the plateau beyond which can indeed only be determined by a survey and properly illustrated by a map. I need hardly say that a topographical delineation of ground derived from observations made by the aid of photography demands as much technical skill on the part of the topographer and as much systematic application of the use of instruments as any other survey. It must be a combination of careful triangulation and skillful plane tabling precisely as is the product of a topographical survey. It demands, if anything, more special training and a more elaborate method of procedure than does ordinary survey. So far as the results of experiments made over suitable fields in Canada can teach us, the verdict is in favor of the process only under certain conditions of light and climate when it is desirable to obtain a record of observations in as short a space of time as possible, either in high altitudes, when passing clouds afford but a fleeting view of the landscape, or in low-lying districts, where active tribal hostility in the field or some similar condition renders it desirable to curtail operations as much as possible.

Under all other ordinary conditions it is maintained by Canadian surveyors that, although both time and labor may be saved on the field operations, the resulting map can never attain the same standard of accuracy in detail that distinguishes good topographical illustration of the usual variety of natural features. I am, of course, now speaking of geographical surveying as an art, not of mere geographical exploitation. In the latter case doubtless every traveler who can "pull the string" in these days can add immensely to the personal interest of his journeys by his illustrations of them. But I would earnestly impress upon all travelers that if they desire those illustrations to be of any use for geographical compilation it is absolutely necessary to know the point from which they were taken and the direction of the view.

BAROMETRIC RECORDS.

Once again, too, would I warn travelers of the utter uncertainty of all classes of barometric determinations for altitude. Very little has been done in recent years toward improving instruments of the barometric class, and meteorological science has not yet taught us how to deal with the constant variations in air pressure produced over local areas by changeable weather. There are some countries where barometric records can hardly be regarded as offering a clue even to differential heights. It can not be too often insisted on that the determination of the relative heights of mountain peaks and of the local value of refraction by means of the theodolite is as much the duty of the triangulator as is the fixing of those peaks in position for the use of the topographer. From these, again, the altitude of positions in the plains can be safely determined by small instruments of the clinometer class without resorting to the barometer at all, although it may still be necessary to ascertain the value of one initial (or final) point which must be determined by many observations spread over a considerable length of time and synchronous with another set of observations determined at sea, or some already known, level. This, of course, will occur only when a new geographical area is opened up to survey at some distance from the sea.

UNIVERSAL MAPPING.

It will be remembered that a scheme was set afloat some years ago by Dr. Penck, the eminent German geographer, for the mapping of the whole world on the scale of one-millionth, which is very nearly equivalent to the scale of 16 miles to 1 inch. Substantial progress has now been made in support of this scheme by English map makers, especially in India, where all the transborder countries which have fallen geographically into the hands of Indian surveyors are now being mapped on this scale. In the commencement of all great colonial survey schemes it is much to be hoped that this project for one homogeneous and universal map will not be lost sight of.

MAP SPELLING.

I wish that we were as well on the way toward homogeneity in spelling as we are in scale, but it is much to be feared that arbitrary rules will have to be applied to so many special localities that no universal system is ever likely to be adopted. The farther that exact geography extends the more difficult becomes this problem, until at last we shall probably arrive at the conclusions adopted long ago by the government of India, and consider it best to lay down by order an arbitrary list of prominent names and rule that the spelling of them shall be maintained as in this list in all Government records and maps. Scientists may disagree, but, after all, it seems the only practical way out of the confusion that exists at present.

TERMINOLOGY.

There is yet another subject of world-wide interest to the geographical student equally with the practical geographer which requires something of the erudition of the philological scholar to be brought to bear upon it in order to arrive at a satisfactory issue. I refer to the subject of geographical terminology. It may seem an easy thing to be satisfied with such general definitions as are involved in the terms "range of mountains," "coast lines," "main channels," "watersheds," "slopes," "affluents," and the like; but when these terms, and terms similar to them, are employed in international agreements and treaties, carrying with them the necessity for identifying on the face of nature the feature which corresponds to the term employed, there is always to be found room for discussion as to what its exact meaning may be; for the variations of nature are infinite, and no two features classified under the same generic name are alike. Were I to give you examples of only a few of the geographical expressions which, carelessly used, have led up to serious international disagreements you would, I am assured, agree with me that it is high time that geographers all the world over came to some definite understanding about the meaning of geographical terms. To take an instance. What is a "range" or a "main range" of mountains? Where does it begin? Where does it end? How far does the term involve geological structure? When a continuous line of similar structure is split across the axis of it, does it become two ranges or does it remain one and the same range? Or, again, what is "the foot of the hills?" Is it where the steep slopes end and the talus or gentle gradients of its detritus commence, or must you follow the latter down to the nearest watercourse? If you talk of the coast line of western Patagonia or of Norway, do you include such headlands as are connected with the mainland at low water and exclude the islands, or do you mean the coast line of both? What is the main channel of a river? Is it where the flowing water scours

deepest from time to time, or is it a fixture among a score of minor channels that shift and change? Perfect definition is, of course, hopeless. It is not in the power of man to deal with all the infinite variations of geographical feature and to classify them as he would specimens of botanical origin or of natural history. But we might arrive at a much more satisfactory dictionary of geographical terms in our own language than at present exists, and we might offer that dictionary to the geographers of the world at large and say, "Here we have at least endeavored to explain our meaning when we make use of geographical expressions. This is what is taught in our schools as the best means of translating the general idea into a distinct mental conception of natural features; and in future when we use these terms you will know on the best authority that England can produce what it is that we mean by them." Then, possibly, instead of having to turn to Germany and France for assistance in expressing ourselves clearly when drawing up legal documents dealing with geographical conditions, we may find the English language become the standard for this special class of literature in spite of its verbal poverty. This, at any rate, is what is now being attempted by the Geographical Society, which spares no effort in order to obtain the best literary assistance in its compilation that the country affords. We shall soon have a geographical dictionary, I trust, and be able to enter with a little more ease and confidence into the field of literary discussion of geographical subjects.

PROGRESS OF GEOGRAPHICAL EDUCATION.

The progress of geographical education in the country, although it is by no means so universally apparent as might be considered desirable, yet shows encouraging symptoms of vitality in many directions.

The Civil School at Oxford, for instance, conducted by Mr. Mackinder, has already made most successful efforts to produce expert teachers of geography. Here, in addition to 163 undergraduates attending courses during the past year, five students have already won the post-graduate diploma granted by the university, and it is encouraging to note that four out of the five have already obtained distinctively geographical work. Others similarly qualified, if of sufficient ability, would probably not have long to wait for opportunities. In addition to its regular university functions, the Oxford school has this year organized a summer course of three weeks' study. This has been well attended by teachers and instructors from all parts of the country, and even from America.

In London a department of economic geography is in course of organization at the School of Economics and Political Science, and geography will become a compulsory subject in examinations. In the

matter of examinations we have to chronicle the issue of a most excellent syllabus for the new London matriculation which should ultimately have great influence on the teaching in many schools.

Further, the Geographical Association, a body now of several hundred teachers, has made great progress. It has recently commenced the issue of a journal known as the "Geographical Teacher," one of whose functions appears to be the criticism of the questions set in various public examinations.

In the University of Cambridge the interests of geography are doubtless not overlooked, but they are not conspicuously in evidence, and I have no trustworthy data of the progress made in their maintenance.

In military schools the report of the late committee appointed to consider the education of army officers shows clearly enough that among all the necessary subjects for a cadet's education which have to be crammed into the exceedingly short course of his military schooling that branch of geography which is embraced by the term "military topography" finds a very conspicuous place. The short course of a military school will never turn out an accomplished geographical surveyor; nor does it in any way outflank the necessity for a military school for professional topographers. But it teaches the young officer how maps are made and instructs him in the use of topographical symbols. It would be well if it could be pushed a little further—if it could teach him how to make use of the maps when they are made—for personal experience convinces me that the apathy shown by many of our foremost generals and leaders on the subject of maps arises chiefly from a well-founded doubt of their own ability to make use of them. As for the broader basis of general geographical instruction which would deal with the distribution of important military posts and strategic positions throughout the Empire and teach officers the functions of such positions, either individually or in combination, during military or naval operations, it is perhaps better that such a strategic aspect of geography should be relegated to a later age, when the average intelligence of the cadet has become more fully developed.

Taking it for all in all, there are distinct signs of a more general interest and more scholarly standard of thought in the subject of geography. This is probably due to the efforts of a comparatively small group of workers at a time of general educational reform, possibly partly stimulated by the disclosures in connection with the late war.

The methods of further improvement are simple—better teachers and better examining—and for both it is probable that we must look more directly to civil sources than to the tentative efforts of the military schools.

THE DISCOVERY OF THE FUTURE.[a]

By H. G. Wells.[b]

It will lead into my subject most conveniently to contrast and separate two divergent types of mind, types which are to be distinguished chiefly by their attitude toward time, and more particularly by the relative importance they attach and the relative amount of thought they give to the future of things.

The first of these two types of mind, and it is, I think, the predominant type, the type of the majority of living people, is that which seems scarcely to think of the future at all, which regards it as a sort of black nonexistence upon which the advancing present will presently write events. The second type, which is, I think, a more modern and much less abundant type of mind, thinks constantly and by preference of things to come, and of present things mainly in relation to the results that must arise from them. The former type of mind, when one gets it in its purity, is retrospective in habit, and it interprets the things of the present, and gives value to this and denies it to that, entirely with relation to the past. The latter type of mind is constructive in habit, it interprets the things of the present and gives value to this or that, entirely in relation to things designed or foreseen. While from that former point of view our life is simply to reap the consequences of the past, from this our life is to prepare the future. The former type one might speak of as the legal or submissive type of mind, because the business, the practice, and the training of a lawyer dispose him toward it; he of all men must most constantly refer to the law made, the right established, the precedent set, and most consistently ignore or condemn the thing that is only seeking to establish itself. The latter type of mind I might for contrast call the legislative, creative, organizing, or masterful type, because it is perpetually attacking and altering the established order of things, perpetually falling away from respect for

[a] Reprinted by permission from "Nature," London, No. 1684, vol. 65, Feb. 6, 1902.

[b] A discourse delivered at the Royal Institution on Friday, January 24, 1902, by Mr. H. G. Wells.

what the past has given us. It sees the world as one great workshop, and the present is no more than material for the future, for the thing that is yet destined to be. It is in the active mood of thought, while the former is in the passive; it is the mind of youth, it is the mind more manifest among the western nations, while the former is the mind of age, the mind of the oriental.

Things have been, says the legal mind, and so we are here. And the creative mind says we are here because things have yet to be.

Now I do not wish to suggest that the great mass of people belong to either of these two types. Indeed, I speak of them as two distinct and distinguishable types mainly for convenience and in order to accentuate their distinction. There are probably very few people who brood constantly upon the past without any thought of the future at all, and there are probably scarcely any who live and think consistently in relation to the future. The great mass of people occupy an intermediate position between these extremes, they pass daily and hourly from the passive mood to the active, they see this thing in relation to its associations and that thing in relation to its consequences, and they do not even suspect that they are using two distinct methods in their minds.

But for all that they are distinct methods, the method of reference to the past and the method of reference to the future, and their mingling in many of our minds no more abolishes their difference than the existence of piebald horses proves that white is black.

I believe that it is not sufficiently recognized just how different in their consequences these two methods are, and just where their difference and where the failure to appreciate their difference takes one. This present time is a period of quite extraordinary uncertainty and indecision upon endless questions—moral questions, æsthetic questions, religious and political questions—upon which we should all of us be happier to feel assured and settled, and a very large amount of this floating uncertainty about these important matters is due to the fact that with most of us these two insufficiently distinguished ways of looking at things are not only present together, but in actual conflict in our minds, in unsuspected conflict; we pass from one to the other heedlessly without any clear recognition of the fundamental difference in conclusions that exists between the two, and we do this with disastrous results to our confidence and to our consistency in dealing with all sorts of things.

But before pointing out how divergent these two types or habits of mind really are, it is necessary to meet a possible objection to what has been said. I may put that objection in this form: Is not this distinction between a type of mind that thinks of the past and of a type of mind that thinks of the future a sort of hair splitting, almost like distinguishing between people who have left hands and people who

have right? Everybody believes that the present is entirely determined by the past you say; but then everybody believes also that the present determines the future. Are we simply separating and contrasting two sides of everybody's opinion? To which one replies that we are not discussing what we know and believe about the relations of past, present, and future, or of the relation of cause and effect to each other in time. We all know the present depends for its causes on the past, and that the future depends for its causes upon the present. But this discussion concerns the way in which we approach things upon this common ground of knowledge and belief. We may all know there is an east and a west, but if some of us always approach and look at things from the west, if some of us always approach and look at things from the east, and if others again wander about with a pretty disregard of direction, looking at things as chance determines, some of us will get to a westward conclusion of this journey, and some of us will get to an eastward conclusion, and some of us will get to no definite conclusion at all about all sorts of important matters. And yet those who are traveling east, and those who are traveling west, and those who are wandering haphazard, may be all upon the same ground of belief and statement and amidst the same assembly of proven facts. Precisely the same thing will happen if you always approach things from the point of view of their causes, or if you approach them always with a view to their probable effects. And in several very important groups of human affairs it is possible to show quite clearly just how widely apart the two methods, pursued each in its purity, take those who follow them.

I suppose that three hundred years ago all people who thought at all about moral questions, about questions of right and wrong, deduced their rules of conduct absolutely and unreservedly from the past, from some dogmatic injunction, some finally settled decree. The great mass of people do so to-day. It is written, they say. Thou shalt not steal, for example—that is the sole, complete, and sufficient reason why you should not steal, and even to-day there is a strong aversion to admit that there is any relation between the actual consequences of acts and the imperatives of right and wrong. Our lives are to reap the fruits of determinate things, and it is still a fundamental presumption of the established morality that one must do right though the heavens fall. But there are people coming into this world who would refuse to call it right if it brought the heavens about our heads, however authoritative its sources and sanctions, and this new disposition is, I believe, a growing one. I suppose in all ages people in a timid, hesitating, guilty way have tempered the austerity of a dogmatic moral code by small infractions to secure obviously kindly ends, but it was, I am told, the Jesuits who first deliberately sought to qualify the

moral interpretation of acts by a consideration of their results. To-day there are few people who have not more or less clearly discovered the future as a more or less important factor in moral considerations. To-day there is a certain small proportion of people who frankly regard morality as a means to an end, as an overriding of immediate and personal considerations out of regard to something to be attained in the future, and who break away altogether from the idea of a code dogmatically established for ever. Most of us are not so definite as that, but most of us are deeply tinged with the spirit of compromise between the past and the future; we profess an unbounded allegiance to the prescriptions of the past, and we practice a general observance of its injunctions, but we qualify to a vague, variable extent with considerations of expediency. We hold, for example, that we must respect our promises. But suppose we find unexpectedly that for one of us to keep a promise, which has been sealed and sworn in the most sacred fashion, must lead to the great suffering of some other human being, must lead, in fact, to practical evil? Would a man do right or wrong if he broke such a promise? The practical decision most modern people would make would be to break the promise. Most would say that they did evil to avoid a greater evil. But suppose it was not such very great suffering we were going to inflict, but only some suffering? And suppose it was a rather important promise? With most of us it would then come to be a matter of weighing the promise, the thing of the past, against this unexpected bad consequence, the thing of the future. And the smaller the overplus of evil consequences the more most of us would vacillate. But neither of the two types of mind we are contrasting would vacillate at all. The legal type of mind would obey the past unhesitatingly, the creative would unhesitatingly sacrifice it to the future. The legal mind would say, "they who break the law at any point break it altogether," while the creative mind would say, "let the dead past bury its dead." It is convenient to take my illustration from the sphere of promises, but it is in the realm of sexual morality that the two methods are most acutely in conflict.

And I would like to suggest that until you have definitely determined either to obey the real or imaginary imperatives of the past, or to set yourself toward the demands of some ideal of the future, until you have made up your mind to adhere to one or other of these two types of mental action in these matters, you are not even within hope of a sustained consistency in the thought that underlies your acts, that in every issue of principle that comes upon you, you will be entirely at the mercy of the intellectual mood that happens to be ascendant at that particular moment in your mind.

In the sphere of public affairs also these two ways of looking at things work out into equally divergent and incompatible consequences. The legal mind insists upon treaties, constitutions, legitimacies, and

charters; the legislative incessantly assails these. Whenever some period of stress sets in, some great conflict between institutions and the forces in things, there comes a sorting between these two types of mind. The legal mind becomes glorified and transfigured in the form of hopeless loyalty, the creative mind inspires revolutions and reconstructions. And particularly is this difference of attitude accentuated in the disputes that arise out of wars. In most modern wars there is no doubt quite traceable on one side or the other a distinct creative idea, a distinct regard for some future consequence; but the main dispute even in most modern wars and the sole dispute in most mediæval wars will be found to be a reference, not to the future, but to the past; to turn upon a question of fact and right. The wars of Plantagenet and Lancastrian England with France, for example, were based entirely upon a dummy claim, supported by obscure legal arguments, upon the crown of France. And the arguments that center about the present war in South Africa ignore any ideal of a great united South African state almost entirely, and quibble this way and that about who began the fighting and what was or was not written in some obscure revision of a treaty a score of years ago; yet beneath the legal issues the broad creative idea has been very apparent in the public mind during this war. It will be found more or less definitely formulated beneath almost all the great wars of the past century, and a comparison of the wars of the nineteenth century with the wars of the middle ages will show, I think, that in this field also there has been a discovery of the future, an increasing disposition to shift the reference and values from things accomplished to things to come.

Yet though foresight creeps into our politics and a reference to consequence into our morality, it is still the past that dominates our lives. But why? Why are we so bound to it? It is into the future we go, to-morrow is the eventful thing for us. There lies all that remains to be felt by us and our children and all those that are dear to us. Yet we marshal and order men into classes entirely with regard to the past, we draw shame and honor out of the past; against the rights of property, the vested interests, the agreements and establishments of the past the future has no rights. Literature is for the most part history or history at one remove, and what is culture but a mold of interpretation into which new things are thrust, a collection of standards, a sort of bed of King Og, to which all new expressions must be lopped or stretched? Our conveniences, like our thoughts, are all retrospective. We travel on roads so narrow that they suffocate our traffic; we live in uncomfortable, inconvenient, life-wasting houses out of a love of familiar shapes and familiar customs and a dread of strangeness, all our public affairs are cramped by local boundaries impossibly restricted and small. Our clothing, our habits of speech, our spelling, our weights and measures, our coinage, our religious and

political theories, all witness to the binding power of the past upon our minds. Yet we do not serve the past as the Chinese have done. There are degrees. We do not worship our ancestors or prescribe a rigid local costume; we venture to enlarge our stock of knowledge, and we qualify the classics with occasional adventures into original thought. Compared with the Chinese we are distinctly aware of the future. But compared with what we might be the past is all our world.

The reason why the retrospective habit, the legal habit, is so dominant, and always has been so predominant, is of course a perfectly obvious one. We follow the fundamental human principle and take what we can get. All people believe the past is certain, defined, and knowable, and only a few people believe that it is possible to know anything about the future. Man has acquired the habit of going to the past because it was the line of least resistance for his mind. While a certain variable portion of the past is serviceable matter for knowledge in the case of everyone, the future is, to a mind without an imagination trained in scientific habits of thought, nonexistent. All our minds are made of memories. In our memories each of us has something that without any special training whatever will go back into the past and grip firmly and convincingly all sorts of workable facts, sometimes more convincingly than firmly. But the imagination, unless it is strengthened by a very sound training in the laws of causation, wanders like a lost child in the blackness of things to come and returns empty.

Many people believe, therefore, that there can be no sort of certainty about the future. You can know no more about the future, I was recently assured by a friend, than you can know which way a kitten will jump next. And to all who hold that view, who regard the future as a perpetual source of convulsive surprises, as an impenetrable, incurable, perpetual blackness, it is right and reasonable to derive such values as it is necessary to attach to things from the events that have certainly happened with regard to them. It is our ignorance of the future and our persuasion that that ignorance is absolutely incurable that alone gives the past its enormous predominance in our thoughts. But through the ages, the long unbroken succession of fortune tellers—and they flourish still—witnesses to the perpetually smoldering feeling that after all there may be a better sort of knowledge—a more serviceable sort of knowledge than that we now possess.

On the whole there is something sympathetic for the dupe of the fortune-teller in the spirit of modern science; it is one of the persuasions that come into one's mind, as one assimilates the broad conceptions of science, that the adequacy of causation is universal; that in absolute fact, if not in that little bubble of relative fact, which constitutes the individual life, in absolute fact the future is just as fixed and

determinate, just as settled and inevitable, just as possible a matter of knowledge as the past. Our personal memory gives us an impression of the superior reality and trustworthiness of things in the past, as of things that have finally committed themselves and said their say, but the more clearly we master the leading conceptions of science the better we understand that this impression is one of the results of the peculiar conditions of our lives, and not an absolute truth. The man of science comes to believe at last that the events of the year A. D. 4000 are as fixed, settled, and unchangeable as the events of the year 1600. Only about the latter he has some material for belief and about the former practically none. And the question arises how far this absolute ignorance of the future is a fixed and necessary condition of human life, and how far some application of intellectual methods may not attenuate even if it does not absolutely set aside the veil between ourselves and things to come. And I am venturing to suggest to you that along certain lines and with certain qualifications and limitations a working knowledge of things in the future is a possible and practicable thing. And in order to support this suggestion I would call your attention to certain facts about our knowledge of the past, and more particularly I would insist upon this, that about the past our range of absolute certainty is very limited indeed. About the past I would suggest we are inclined to overestimate our certainty, just as I think we are inclined to underestimate the certainties of the future. And such a knowledge of the past as we have is not all of the same sort or derived from the same sources. Let us consider just what an educated man of to-day knows of the past. First of all he has the realest of all knowledge—the knowledge of his own personal experiences, his memory. Uneducated people believe their memories absolutely, and most educated people believe them with a few reservations. Some of us take up a critical attitude even toward our own memories; we know that they not only sometimes drop things out, but that sometimes a sort of dreaming or a strong suggestion will put things in. But for all that, memory remains vivid and real as no other knowledge can be, and to have seen and heard and felt is to be nearest to absolute conviction. Yet our memory of direct impressions is only the smallest part of what we know. Outside that bright area comes knowledge of a different order—the knowledge brought to us by other people. Outside our immediate personal memory there comes this wider area of facts or quasi facts told us by more or less trustworthy people, told us by word of mouth or by the written word of living and of dead writers. This is the past of report, rumor, tradition, and history—the second sort of knowledge of the past. The nearer knowledge of this sort is abundant and clear and detailed, remoter it becomes vaguer, still more remotely in time and space it dies down to brief, imperfect inscriptions and enigmatical traditions, and at last dies away,

so far as the records and traditions of humanity go, into a doubt and darkness as black, just as black, as futurity. And now let me remind you that this second zone of knowledge outside the bright area of what we have felt and witnessed and handled for ourselves—this zone of hearsay and history and tradition - completed the whole knowledge of the past that was accessible to Shakespeare, for example. To these limits man's knowledge of the past was absolutely confined save for some inklings and guesses, save for some small, almost negligible beginnings, until the nineteenth century began. Besides the correct knowledge in this scheme of hearsay and history a man had a certain amount of legend and error that rounded off the picture in a very satisfying and misleading way, according to Bishop Ussher, just exactly 4004 years B. C. And that was man's universal history—that was his all—until the scientific epoch began. And beyond those limits—? Well, I suppose the educated man of the sixteenth century was as certain of the nonexistence of anything before the creation of the world as he was, and as most of us are still, of the practical nonexistence of the future, or at any rate he was as satisfied of the impossibility of knowledge in the one direction as in the other.

But modern science, that is to say the relentless systematic criticism of phenomena, has in the past hundred years absolutely destroyed the conception of a finitely distant beginning of things; has abolished such limits to the past as a dated creation set, and added an enormous vista to that limited sixteenth century outlook. And what I would insist upon is that this further knowledge is a new kind of knowledge, obtained in a new kind of a way. We know to-day, quite as confidently and in many respects more intimately than we know Sargon or Zenobia or Caractacus, the form and the habits of creatures that no living being has ever met, that no human eye has ever regarded, and the character of scenery that no man has ever seen or can ever possibly see; we picture to ourselves the labyrinthodon raising its clumsy head above the waters of the carboniferous swamps in which he lived, and we figure the pterodactyls, those great bird lizards, flapping their way athwart the forests of the Mesozoic age with exactly the same certainty as that with which we picture the rhinoceros or the vulture. I doubt no more about the facts in this further picture than I do about those in the nearest. I believe in the megatherium which I have never seen as confidently as I believe in the hippopotamus that has engulfed buns from my hand. A vast amount of detail in that further picture is now fixed and finite for all time. And a countless number of investigators are persistently and confidently enlarging, amplifying, correcting, and pushing further and further back the boundaries of this greater past—this prehuman past—that the scientific criticism of existing phenomena has discovered and restored and brought for the first time into the world of human thought. We have become possessed of a new and

once unsuspected history of the world—of which all the history that was known, for example, to Dr. Johnson is only the brief concluding chapter; and even that concluding chapter has been greatly enlarged and corrected by the exploring archæologists working strictly upon the lines of the new method—that is to say, the comparison and criticism of suggestive facts.

I want particularly to insist upon this, that all this outer past—this nonhistorical past—is the product of a new and keener habit of inquiry, and no sort of revelation. It is simply due to a new and more critical way of looking at things. Our knowledge of the geological past, clear and definite as it has become, is of a different and lower order than the knowledge of our memory, and yet of a quite practicable and trustworthy order—a knowledge good enough to go upon; and if one were to speak of the private memory as the personal past, as the next wider area of knowledge as the traditional or historical past, then one might call all that great and inspiring background of remoter geological time the inductive past.

And this great discovery of the inductive past was got, by the discussion and rediscussion and effective criticism of a number of existing facts, odd-shaped lumps of stone, streaks and bandings in quarries and cliffs, anatomical and developmental details that had always been about in the world, that had been lying at the feet of mankind so long as mankind had existed, but that no one had ever dreamed before could supply any information at all, much more reveal such astounding and enlightening vistas. Looked at in a new way they became sources of dazzling and penetrating light. The remoter past lit up and became a picture. Considered as effects, compared and criticised, they yielded a clairvoyant vision of the history of interminable years.

And now, if it has been possible for men by picking out a number of suggestive and significant looking things in the present, by comparing them, criticising them, and discussing them, with a perpetual insistence upon why? without any guiding tradition, and indeed in the teeth of established beliefs, to construct this amazing search light of inference into the remoter past, is it really, after all, such an extravagant and hopeless thing to suggest that, by seeking for operating causes instead of for fossils, and by criticising them as persistently and thoroughly as the geological record has been criticised, it may be possible to throw a search light of inference forward instead of backward, and to attain to a knowledge of coming things as clear, as universally convincing, and infinitely more important to mankind than the clear vision of the past that geology has opened to us during the nineteenth century?

Let us grant that anything to correspond with the memory, anything having the same relation to the future that memory has to the past, is out of the question. We can not imagine, of course, that we can ever

know any personal future to correspond with our personal past, or any traditional future to correspond with our traditional past; but the possibility of an inductive future to correspond with that great inductive past of geology and archæology is an altogether different thing.

I must confess that I believe quite firmly that an inductive knowledge of a great number of things in the future is becoming a human possibility. I believe that the time is drawing near when it will be possible to suggest a systematic exploration of the future. And you must not judge the practicability of this enterprise by the failures of the past. So far nothing has been attempted, so far no first-class mind has ever focused itself upon these issues; but suppose the laws of social and political development, for example, were given as many brains, were given as much attention, criticism, and discussion as we have given to the laws of chemical combination during the last fifty years, what might we not expect?

To the popular mind of to-day there is something very difficult in such a suggestion, soberly made. But here, in this Institution which has watched for a whole century over the splendid adolescence of science, and where the spirit of science is surely understood, you will know that as a matter of fact prophecy has always been inseparably associated with the idea of scientific research. The popular idea of scientific investigation is a vehement, aimless collection of little facts, collected as the bower bird collects shells and pebbles, in methodical little rows, and out of this process, in some manner unknown to the popular mind, certain conjuring tricks—the celebrated wonders of science—in a sort of accidental way emerge. The popular conception of all discovery is accident. But you will know that the essential thing in the scientific process is not the collection of facts, but the analysis of facts. Facts are the raw material and not the substance of science. It is analysis that has given us all ordered knowledge, and you know that the aim and the test and the justification of the scientific process is not a marketable conjuring trick, but prophecy. Until a scientific theory yields confident forecasts you know it is unsound and tentative; it is mere theorizing, as evanescent as art talk or the phantoms politicians talk about. The splendid body of gravitational astronomy, for example, establishes itself upon the certain forecast of stellar movements, and you would absolutely refuse to believe its amazing assertions if it were not for these same unerring forecasts. The whole body of medical science aims, and claims the ability, to diagnose. Meteorology constantly and persistently aims at prophecy, and it will never stand in a place of honor until it can certainly foretell. The chemist forecasts elements before he meets them—it is very properly his boast—and the splendid manner in which the mind of Clerk Maxwell reached in front of all experiment and foretold those things that Marconi has materialized is familiar to us all.

And if I am right in saying that science aims at prophecy, and if the specialist in each science is in fact doing his best now to prophesy within the limits of his field, what is there to stand in the way of our building up this growing body of forecast into an ordered picture of the future that will be just as certain, just as strictly science, and perhaps just as detailed as the picture that has been built up within the last hundred years to make the geological past? Well, so far and until we bring the prophecy down to the affairs of man and his children, it is just as possible to carry induction forward as back; it is just as simple and sure to work out the changing orbit of the earth in the future until the tidal drag hauls one unchanging face at last toward the sun as it is to work back to its blazing and molten past. Until man comes in, the inductive future is as real and convincing as the inductive past. But inorganic forces are the smaller part and the minor interest in this concern. Directly man becomes a factor the nature of the problem changes, and our whole present interest centers on the question whether man is, indeed, individually and collectively incalculable, a new element which entirely alters the nature of our inquiry and stamps it at once as vain and hopeless, or whether his presence complicates, but does not alter, the essential nature of the induction. How far may we hope to get trustworthy inductions about the future of man?

Well, I think, on the whole, we are inclined to underrate our chance of certainties in the future, just as I think we are inclined to be too credulous about the historical past. The vividness of our personal memories, which are the very essence of reality to us, throws a glamor of conviction over tradition and past inductions. But the personal future must in the very nature of things be hidden from us so long as time endures, and this black ignorance at our very feet—this black shadow that corresponds to the brightness of our memories behind us—throws a glamor of uncertainty and unreality over all the future. We are continually surprising ourselves by our own will or want of will; the individualities about us are continually producing the unexpected, and it is very natural to reason that as we can never be precisely sure before the time comes what we are going to do and feel, and if we can never count with absolute certainty upon the acts and happenings even of our most intimate friends, how much the more impossible is it to anticipate the behavior in any direction of states and communities?

In reply to which I would advance the suggestion that an increase in the number of human beings considered may positively simplify the case instead of complicating it; that as the individuals increase in number they begin to average out. Let me illustrate this point by a comparison. Angular pit sand has grains of the most varied shapes. Examined microscopically, you will find all sorts of angles and outlines and variations. Before you look you can say of no particular

grain what its outline will be. And if you shoot a load of such sand from a cart you can not foretell with any certainty where any particular grain will be in the heap that you make; but you can tell—you can tell pretty definitely—the form of the heap as a whole. And further, if you pass that sand through a series of shoots and finally drop it some distance to the ground, you will be able to foretell that grains of a certain sort of form and size will for the most part be found in one part of the heap and grains of another sort of form and size will be found in another part of the heap. In such a case, you see, the thing as a whole may be simpler than its component parts, and this I submit is also the case in many human affairs. So that because the individual future eludes us completely that is no reason why we should not aspire to, and discover and use, safe and serviceable generalizations upon countless important issues in the human destiny.

But there is a very grave and important-looking difference between a load of sand and a multitude of human beings, and this I must face and examine. Our thoughts and wills and emotions are contagious. An exceptional sort of sand grain, a sand grain that was exceptionally big and heavy, for example, exerts no influence worth considering upon any other of the sand grains in the load. They will fall and roll and heap themselves just the same whether that exceptional grain is with them or not; but an exceptional man comes into the world, a Cæsar or a Napoleon or a Peter the Hermit, and he appears to persuade and convince and compel and take entire possession of the sand heap—I mean the community—and to twist and alter its destinies to an almost unlimited extent. And if this is indeed the case, it reduces our project of an inductive knowledge of the future to very small limits. To hope to foretell the birth and coming of men of exceptional force and genius is to hope incredibly, and if, indeed, such exceptional men do as much as they seem to do in warping the path of humanity, our utmost prophetic limit in human affairs is a conditional sort of prophecy. If people do so and so, we can say, then such and such results will follow, and we must admit that that is our limit.

But everybody does not believe in the importance of the leading man. There are those who will say that the whole world is different by reason of Napoleon. But there are also those who will say the whole world of to-day would be very much as it is now if Napoleon had never been born. There are those who believe entirely in the individual man and those who believe entirely in the forces behind the individual man, and for my own part I must confess myself a rather extreme case of the latter kind. I must confess I believe that if by some juggling with space and time Julius Cæsar, Napoleon, Edward IV, William the Conqueror, Lord Rosebery, and Robert Burns had all been changed at birth it would not have produced any serious dislocation of the course of destiny. I believe that these great men of

ours are no more than images and symbols and instruments taken, as it were, haphazard by the incessant and consistent forces behind them; they are the pen nibs Fate has used for her writing, the diamonds upon the drill that pierces through the rock. And the more one inclines to this trust in forces the more one will believe in the possibility of a reasoned inductive view of the future that will serve us in politics, in morals, in social contrivances, and in a thousand spacious ways. And even those who take the most extreme and personal and melodramatic view of the ways of human destiny, who see life as a tissue of fairy godmother births and accidental meetings and promises and jealousies, will, I suppose, admit there comes a limit to these things—that at last personality dies away and the greater forces come to their own. The great man, however great he be, can not set back the whole scheme of things; what he does in right and reason will remain and what he does against the greater creative forces will perish. We can not foresee him; let us grant that. His personal difference, the splendor of his effect, his dramatic arrangement of events will be his own—in other words, we can not estimate for accidents and accelerations and delays—but if only we throw our web of generalization wide enough, if only we spin our rope of induction strong enough, the final result of the great man, his ultimate surviving consequences, will come within our net.

Such, then, is the sort of knowledge of the future that I believe is attainable and worth attaining. I believe that the deliberate direction of historical study and of economic and social study toward the future, and an increasing reference, a deliberate and courageous reference, to the future in moral and religious discussion, would be enormously stimulating and enormously profitable to our intellectual life. I have done my best to suggest to you that such an enterprise is now a serious and practicable undertaking. But at the risk of repetition I would call your attention to the essential difference that must always hold between our attainable knowledge of the future and our existing knowledge of the past. The portion of the past that is brightest and most real to each of us is the individual past—the personal memory. The portion of the future that must remain darkest and least accessible is the individual future. Scientific prophecy will not be fortune telling, whatever else it may be. Those excellent people who cast horoscopes, those illegal fashionable palm-reading ladies who abound so much to-day, in whom nobody is so foolish as to believe, and to whom everybody is foolish enough to go, need fear no competition from the scientific prophets. The knowledge of the future we may hope to gain will be general and not individual; it will be no sort of knowledge that will either hamper us in the exercise of our individual free will or relieve us of our personal responsibility.

And now, how far is it possible at the present time to speculate on

the particular outline the future will assume when it is investigated in this way?

It is interesting, before we answer that question, to take into account the speculations of a certain sect and culture of people who already, before the middle of last century, had set their faces toward the future as the justifying explanation of the present. These were the positivists, whose position is still most eloquently maintained and displayed by Mr. Frederic Harrison, in spite of the great expansion of the human outlook that has occurred since Comte. If you read Mr. Harrison, and if you are also, as I presume your presence here indicates, saturated with that new wine of more spacious knowledge that has been given the world during the last fifty years, you will have been greatly impressed by the peculiar limitations of the positivist conception of the future. So far as I can gather, Comte was, for all practical purposes, totally ignorant of that remoter past outside the past that is known to us by history, or if he was not totally ignorant of its existence, he was, and conscientiously remained, ignorant of its relevancy to the history of humanity. In the narrow and limited past he recognized men had always been like the men of to-day; in the future he could not imagine that they would be anything more than men like the men of to-day. He perceived, as we all perceive, that the old social order was breaking up, and after a richly suggestive and incomplete analysis of the forces that were breaking it up he set himself to plan a new static social order to replace it. If you will read Comte, or, what is much easier and pleasanter, if you will read Mr. Frederic Harrison, you will find this conception constantly apparent—that there was once a stable condition of society with humanity, so to speak, sitting down in an orderly and respectable manner; that humanity has been stirred up and is on the move, and that finally it will sit down again on a higher plane, and for good and all, cultured and happy, in the reorganized positivist state. And since he could see nothing beyond man in the future, there, in that millennial fashion, Comte had to end. Since he could imagine nothing higher than man, he had to assert that humanity, and particularly the future of humanity, was the highest of all conceivable things.

All that was perfectly comprehensible in a thinker of the first half of the nineteenth century. But we of the early twentieth, and particularly that growing majority of us who have been born since the Origin of Species was written, have no excuse for any such limited vision. Our imaginations have been trained upon a past in which the past that Comte knew is scarcely more than the concluding moment. We perceive that man, and all the world of men, is no more than the present phase of a development so great and splendid that beside this vision epics jingle like nursery rhymes, and all the exploits of humanity shrivel to the proportion of castles in the sand. We look back through

countless millions of years and see the great will to live struggling out of the intertidal slime, struggling from shape to shape and from power to power, crawling and then walking confidently upon the land, struggling generation after generation to master the air, creeping down into the darkness of the deep; we see it turn upon itself in rage and hunger and reshape itself anew; we watch it draw nearer and more akin to us, expanding, elaborating itself, pursuing its relentless, inconceivable purpose, until at last it reaches us and its being beats through our brains and arteries, throbs and thunders in our battle ships, roars through our cities, sings in our music, and flowers in our art. And when, from that retrospect, we turn again toward the future, surely any thought of finality, any millennial settlement of cultured persons, has vanished from our minds.

This fact that man is not final is the great unmanageable, disturbing fact that rises upon us in the scientific discovery of the future, and to my mind, at any rate, the question what is to come after man is the most persistently fascinating and the most insoluble question in the whole world.

Of course we have no answer. Such imaginations as we have refuse to rise to the task.

But for the nearer future, while man is still man, there are a few general statements that seem to grow more certain. It seems to be pretty generally believed to-day that our dense populations are in the opening phase of a process of diffusion and aëration. It seems pretty inevitable also that at least the mass of white population in the world will be forced some way up the scale of education and personal efficiency in the next two or three decades. It is not difficult to collect reasons for supposing—and such reasons have been collected—that in the near future, in a couple of hundred years, as one rash optimist has written, or in a thousand or so, humanity will be definitely and consciously organizing itself as a great world state—a great world state that will purge from itself much that is mean, much that is bestial, and much that makes for individual dullness and dreariness, grayness and wretchedness in the world of to-day; and although we know that there is nothing final in that world state, although we see it only as something to be reached and passed, although we are sure there will be no such sitting down to restore and perfect a culture as the positivists foretell, yet few people can persuade themselves to see anything beyond that except in the vaguest and more general terms. That world state of more efficient, more vivid, beautiful, and eventful people is, so to speak, on the brow of the hill, and we can not see over, though some of us can imagine great uplands beyond and something, something that glitters elusively, taking first one form and then another, through the haze. We can see no detail, we can see nothing definable, and it is simply, I know, the sanguine necessity of our minds that makes us

believe those uplands of the future are still more gracious and splendid than we can either hope or imagine. But of things that can be demonstrated we have none.

Yet I suppose most of us entertain certain necessary persuasions, without which a moral life in this world is neither a reasonable nor a possible thing. All this paper is built finally upon certain negative beliefs that are incapable of scientific establishment. Our lives and powers are limited, our scope in space and time is limited, and it is not unreasonable that for fundamental beliefs we must go outside the sphere of reason and set our feet upon faith. Implicit in all such speculations as this, is a very definite and quite arbitrary belief, and that belief is that neither humanity nor in truth any individual human being is living its life in vain. And it is entirely by an act of faith that we must rule out of our forecasts certain possibilities, certain things that one may consider improbable and against the chances, but that no one upon scientific grounds can call impossible. One must admit that it is impossible to show why certain things should not utterly destroy and end the entire human race and story, why night should not presently come down and make all our dreams and efforts vain. It is conceivable, for example, that some great unexpected mass of matter should presently rush upon us out of space, whirl sun and planets aside like dead leaves before the breeze, and collide with and utterly destroy every spark of life upon this earth. So far as positive human knowledge goes, this is a conceivably possible thing. There is nothing in science to show why such a thing should not be. It is conceivable, too, that some pestilence may presently appear, some new disease, that will destroy, not 10 or 15 or 20 per cent of the earths' inhabitants as pestilences have done in the past, but 100 per cent, and so end our race. No one, speaking from scientific grounds alone, can say, That can not be. And no one can dispute that some great disease of the atmosphere, some trailing cometary poison, some great emanation of vapor from the interior of the earth, such as Mr. Shiel has made a brilliant use of in his "Purple Cloud," is consistent with every demonstrated fact in the world. There may arise new animals to prey upon us by land and sea, and there may come some drug or a wrecking madness into the minds of men. And finally, there is the reasonable certainty that this sun of ours must some day radiate itself toward extinction; that, at least, must happen; it will grow cooler and cooler, and its planets will rotate ever more sluggishly until some day this earth of ours, tideless and slow moving, will be dead and frozen, and all that has lived upon it will be frozen out and done with. There surely man must end. That of all such nightmares is the most insistently convincing.

And yet one doesn't believe it.

At least I do not. And I do not believe in these things because I

have come to believe in certain other things—in the coherency and purpose in the world and in the greatness of human destiny. Worlds may freeze and suns may perish, but there stirs something within us now that can never die again.

Do not misunderstand me when I speak of the greatness of human destiny.

If I may speak quite openly to you, I will confess that, considered as a final product, I do not think very much of myself or (saving your presence) my fellow-creatures. I do not think I could possibly join in the worship of humanity with any gravity or sincerity. Think of it. Think of the positive facts. There are surely moods for all of us when one can feel Swift's amazement that such a being should deal in pride. There are moods when one can join in the laughter of Democritus; and they would come oftener were not the spectacle of human littleness so abundantly shot with pain. But it is not only with pain that the world is shot—it is shot with promise. Small as our vanity and carnality makes us, there has been a day of still smaller things. It is the long ascent of the past that gives the lie to our despair. We know now that all the blood and passion of our life was represented in the Carboniferous time by something—something, perhaps, cold-blooded and with a clammy skin, that lurked between air and water, and fled before the giant amphibia of those days.

For all the folly, blindness, and pain of our lives, we have come some way from that. And the distance we have traveled gives us some earnest of the way we have yet to go.

Why should things cease at man? Why should not this rising curve rise yet more steeply and swiftly? There are many things to suggest that we are now in a phase of rapid and unprecedented development. The conditions under which men live are changing with an ever-increasing rapidity, and, so far as our knowledge goes, no sort of creatures have ever lived under changing conditions without undergoing the profoundest changes themselves. In the past century there was more change in the conditions of human life than there had been in the previous thousand years. A hundred years ago inventors and investigators were rare scattered men, and now invention and inquiry is the work of an organized army. This century will see changes that will dwarf those of the nineteenth century, as those of the nineteenth dwarf those of the eighteenth. One can see no sign anywhere that this rush of change will be over presently, that the positivist dream of a social reconstruction and of a new static culture phase will ever be realized. Human society never has been quite static, and it will presently cease to attempt to be static. Everything seems pointing to the belief that we are entering upon a progress that will go on, with an ever widening and ever more confident stride, forever. The reorganization of society that is going on now beneath the traditional appearance of things is a kinetic reorganization. We are getting into

marching order. We have struck our camp forever and we are out upon the roads.

We are in the beginning of the greatest change that humanity has ever undergone. There is no shock, no epoch-making incident—but then there is no shock at a cloudy daybreak. At no point can we say, Here it commences, now; last minute was night and this is morning. But insensibly we are in the day. If we care to look, we can foresee growing knowledge, growing order, and presently a deliberate improvement of the blood and character of the race. And what we can see and imagine gives us a measure and gives us faith for what surpasses the imagination.

It is possible to believe that all the past is but the beginning of a beginning, and that all that is and has been is but the twilight of the dawn. It is possible to believe that all that the human mind has ever accomplished is but the dream before the awakening. We can not see, there is no need for us to see, what this world will be like when the day has fully come. We are creatures of the twilight. But it is out of our race and lineage that minds will spring, that will reach back to us in our littleness to know us better than we know ourselves, and that will reach forward fearlessly to comprehend this future that defeats our eyes. All this world is heavy with the promise of greater things, and a day will come, one day in the unending succession of days, when beings, beings who are now latent in our thoughts and hidden in our loins, shall stand upon this earth as one stands upon a footstool, and shall laugh and reach out their hands amidst the stars.

THE LIFE OF MATTER.[a]

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APPARENT DIFFERENCES BETWEEN LIVING AND BRUTE BODIES—THE TWO KINGDOMS.

That there should be any essential similarity between an inanimate object and a living being seems at first impossible. What resemblances can be discovered between a stone, a lion, and an oak? A comparison of the inert and immovable pebble with the animal that bounds and the plant that each year extends its foliage gives an impression of strong contrast. Between the organic and the inorganic worlds is an apparent abyss.

The first impressions we receive confirm this view; superficial studies furnish arguments for it. There is thus created in the mind of the child, and later in that of man, a sharply marked distinction between the natural objects of the mineral kingdom on the one hand and those of the two kingdoms of living beings on the other.

But a more intimate knowledge tends every day to throw doubt upon the strictness or absolute character of such distinction. It shows that gross or brute matter can no longer be placed on one side and living beings on the other. Scientists deliberately speak of "the life of matter," which seems to the uninstructed a contradiction in terms. They discover in certain classes of mineral bodies almost all the attributes of life. They find in others fainter, yet recognizable, indications of an undeniable relationship.

We propose to pass in review these analogies and resemblances, as has already been done in a fairly complete manner by MM. Léo Errera, Ch. Ed. Guillaume, L. Bourdeau, Ed. Griffon, and others. We will take as guides the excellent studies of Rauber, of Ostwald, and of Tammann upon crystals and crystalline germs, studies which are merely a continuation of those of Pasteur and of Gernez. These show that crystalline bodies are endowed with the principal attributes of living beings—that is to say, with a definite form, an apitude for acquiring it, and for reestablishing it by repairing mutilations that

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may be inflicted upon it; a nutritive increase in size at the expense of the mother liquor which constitutes its culture medium; finally, a still more incredible property, all the characteristics of reproduction by generation. Other curious facts observed by skillful physicists—W. Roberts-Austen, W. Spring, Stead, Osmond, Guillemin, Charpy, Ch. Ed. Guillaumè show that the immutability and immobility of bodies supposed to be the most rigid, such as glass, the metals, steel, and brass, are only false appearances. Beneath the surface of the metal that seems to us inert there is struggling a swarming population of molecules that displace each other, move about, and arrange themselves so as to form definite figures, taking on forms adapted to the conditions of the environment. Sometimes it is years before they arrive at a state of ultimate and final equilibrium which is that of eternal rest.

However, in order to understand these facts and their interpretation it is necessary to recall the fundamental characteristics of living beings. These are precisely the ones which it is believed have been found in inanimate matter.

I.

UNIVERSAL LIFE—OPINIONS OF THE PHILOSOPHERS AND POETS.

1. PRIMITIVE BELIEFS: IDEAS OF THE POETS.

The teachings of science regarding the analogies between brute bodies and living bodies accord with the conceptions of the philosophers and the fancies of the poets. The ancients conceived that all bodies in nature, both living and inert, were the constituent parts of a universal organism, the macrocosm, which they compared to the human microcosm. They attributed to it a principle of action, the *psyche*, analogous to the vital principle, which directed phenomena, and an intelligent principle, the *nous*, analogous to the soul, which comprehended them. This universal life or this universal soul played an important part in their metaphysical system. It was the same with the poets. Their tendency has always been to animate nature for the purpose of bringing her into harmony with our thoughts and feelings. They seek to discover the life or soul hidden at the bottom of things.

> List to the voices. Everything has voice.
> Winds, waves, and flames, trees, reeds, and rocks rejoice.
> They live, indeed, each thing instinct with soul.

After making proper allowance for emotional exaggeration, ought we to consider these ideas as the prophetic divination of a truth which science is only just beginning to dimly perceive? Not at all. As Renan has said, this universal animism, instead of being a product of refined reflection, is merely a legacy from the most primitive of mental processes, a remnant of conceptions belonging to the childhood of

humanity. It recalls the time when men conceived external things only in terms of themselves, when they made from each object of nature a living being. Thus they personified the sky, the earth, the sea, the mountain, the rivers, the fountains, and the fields. They likened to animate voices the murmur of the forest:

> * * * The oak chides and the birch
> Is whispering. * * *
> And the beech murmurs. There are voices low
> Lost in the willow's shiver, slight, half-heard:
> While the lone pine tree moans some mystic word.

For primitive man, as for the poet of all times, everything is alive, and every voice, every noise, is the expression of the activity of a living being who has feelings similar to our own. The sighing of the breeze, the moan of the wave upon the strand, the babbling of the brook, the roaring of the sea, and the pealing of the thunder are nothing less than sad, joyous, or angry, living voices.

These impressions were embodied in a mythology whose pleasing features can not conceal its inadequacy. Then they passed into philosophy and approached the field of science. Thales believed that all bodies in nature were animate and living. Origen considered all the stars as actual beings. Even Kepler himself endowed with animate life all the bodies of nature. He especially attributed to the celestial bodies an interior principle of action, which, it may be said in passing, is contrary to the law of the inertia of matter, which has wrongly been ascribed to him to the detriment of Galileo. The terrestrial globe was, according to him, a great animal, sensitive to astral influences, frightened at the approach of other planets, and manifesting its terror by tempests, hurricanes, and earthquakes. The wonderful flux and reflux of the ocean was its breathing. The earth had its blood, its perspiration, its excretions; it also had its foods, among which was the sea water which it absorbed by numerous channels. It should be said that at the end of his life Kepler retracted these vague dreams, ascribing them to the influence of J. C. Scaliger. He explained that by the soul of the celestial bodies he meant nothing but their motive force.

2. OPINION OF THE PHILOSOPHERS.

Transition from brute to living bodies.—The lowering of the barrier between brute bodies and living bodies began with those philosophers who introduced into the world the great principles of continuity and evolution.

The principle of continuity.—Among these Leibnitz should be placed first. According to the doctrine of that illustrious philosopher, as interpreted by M. Fouillée, "there is no inorganic kingdom; only a great organic kingdom, of which mineral, vegetable, and animal forms are the various developments. * * * Continuity exists everywhere

throughout the world, and life, together with organization, also exists everywhere. Nothing is dead; life is universal." It results from this that there is no interruption or break in the succession of natural phenomena; that everything develops gradually, and, finally, that the origin of the organic being must be sought in the inorganic. Life, properly so called, has not in fact always existed on the surface of the globe. It appeared there at a certain geologic epoch, in a purely inorganic medium, by reason of favorable conditions. The doctrine of continuity obliges us, however, to admit that it preexisted there under some rudimentary form.

The modern philosophers who are imbued with the same principles, MM. Fouillée, L. Bourdeau, and A. Sabatier, express themselves in terms like those of Leibnitz. "Dead matter and living matter are not two absolutely different entities, but represent two forms of the same matter, differing only in degree, sometimes but very little." When there is only a question of degree it can not be held that there is an opposition. We ought not to take inequalities for contrary attributes, renewing here the error that leads the vulgar mind to consider heat and cold as objective states qualitatively opposed to each other.

Continuity by transition.—The reasoning which induces us to remove the barrier between the two kingdoms and to consider that minerals are endowed with a sort of rudimentary life is the same as that which obliges us to admit that there is no fundamental difference between other natural phenomena. There are transitions between that which lives and that which does not, between the animate being and the brute body. There are even such transitions between that which thinks and that which does not think, between thought and no thought, between the conscious and the unconscious. This idea of insensible transition, of continuous passage between apparent opposites, raises, at first, insurmountable resistance in minds not prepared for it by a long comparison of facts. It is slowly realized and at last accepted by those who, in the world of things, follow the infinity of gradations which natural phenomena present. The principle of continuity comes at last to constitute, as one may say, a sort of mental attitude. The man of science may, then, be led, like the philosopher, to entertain the idea of a rudimentary form of life that animates matter. He may, like the philosopher, be guided by this idea; he may attribute a priori to brute matter all the really essential qualities of living beings. But this must be on the condition that he must afterwards demonstrate these attributed qualities by means of observation and experimentation. He must show that molecules and atoms, far from being inert and dead masses, are in reality active elements, endowed with a sort of inferior life, which is manifested by all the mutations that are observed in brute matter: by attractions and repulsions, by move-

ments in response to exterior stimulations, by variations in state and of equilibrium; finally, by the systematic methods by which these elements group themselves, conforming to definite types of structure and producing different species of chemical compounds.

Continuity by summation.—The idea of summation leads by another way to the same result. It is another form of the principle of continuity. A totality of effects, obscure and indistinct in themselves, produces a phenomenon appreciable, perceptible, and distinct, seemingly heterogeneous in its components without, however, being so. The manifestations of atomic or molecular activity thus become manifestations of vital activity.

This is another consequence of the Leibnitzian doctrine. For, according to that philosophical doctrine, individual consciousness, like individual life, is the collective expression of a multitude of elementary lives or consciousnesses, inappreciable because of their low degree, and the real phenomenon is found to be the sum, or rather the integral, of all these insensible effects. The elementary consciousnesses are harmonized, unified, integrated in an effect that becomes manifest, in the same way as "the noises of waves, not one of which would be heard if by itself, yet, when united together and perceived at the same instant, become the resounding voice of ocean."

Ideas of the philosophers as to sensibility and consciousness in brute bodies.—The philosophers have gone still further in the way of analogies, and have recognized in the play of the forces of brute matter, particularly in the play of the chemical forces, a humble rudiment of the appetences and tendencies that regulate, in their opinion, the functional activity of living beings—a trace, as it were, of their sensibility. The reactions of matter indicate, in their eyes, the existence of a sort of hedonic consciousness, that is to say, a consciousness reduced simply to apprehension of distinction between well-being and its opposite, a desire for good and repulsion from harm, which they suppose to be the universal principle in the activity of things. This was the opinion of Empedocles in antiquity, it was that of Diderot, of Cabanis, and, in general, that of the modern materialistic school, eager to find, even in the most degraded representatives of the inorganic world, the first traces of the vitality and intellectual life which blossoms out at the top of the living world.

Similar ideas are clearly apparent in the early history of all natural sciences. It was this same principle of appetition, or of love and repulsion, or hate, that, under the names of affinity, selection, and incompatibility, was thought to direct the mutations of bodies at the time of the origin of chemistry; when Boerhaave, for example, compared chemical combinations to voluntary and conscious alliances, in which the respective elements, drawn together by sympathy, contracted appropriate marriages.

General principle of the homogeneity of the complex and its constituents. —The assimilation of brute bodies to living bodies, and of the inorganic kingdom to the organic, was, in the mind of these philosophers, the natural consequence of positing a priori the principles of continuity and evolution. There is, however, a principle underlying these principles.

This principle is not expressed in an explicit manner by the philosophers; it is not formulated in precise terms, but is more or less unconsciously implied; it is everywhere applied. It, however, appears clearly behind their apparatus of philosophical reasoning. It is the affirmation that no arrangement or combination of elements can put forth any new activity essentially different from the activities of the elements of which it is composed. Man is a living clay, say Diderot and Cabanis, and, on the other hand, he is a thinking being. As it is impossible to produce that which thinks from that which does not think, the clay must possess a rudiment of thought. But is there not another alternative? May not the new phenomenon, thought, be the effect of the arrangement of this clay? If we exclude this alternative we must then consider that arrangement and organization are incapable of producing in arranged and organized matter a new property different from that which it presented before such arrangement.

Living protoplasm, says another, is merely an assemblage of brute elements; "these brute elements must, therefore, possess a rudiment of life." This is the same implied supposition which we have just considered; if life is not the basis of each element it can not result from their simple assemblage.

Man and animals are combinations of atoms, says M. Le Dantec. It is more natural to admit that human consciousness is the result of the elementary consciousnesses of the constituent atoms than to consider it as resulting from mere construction derived from elements destitute of any trace of consciousness. "Life," says Haeckel, "is universal; we could not conceive its existence in definite aggregates of matter if it did not belong to their constituent elements." This time the postulate is almost expressed.

The reasoning is always the same; there are even the same words; the fundamental hypothesis is the same; only it remains more or less unexpressed, more or less unperceived. It may be stated as follows:

Arrangement, assemblage, construction, and aggregation are powerless to develop, in a complex, anything new, essentially heterogeneous to what already exists in the elements. Reciprocally, grouping brings out in a complex a property which is the gradual development of an analogous property in the elements. It is in this sense that there exists a collective soul in crowds, of which the manifestations have been set forth by M. G. Le Bon. In the same way many sociologists, adopting the idea advanced by P. de Lilienfeld in 1865, attribute to

nations a certain formal individuality, following the type of that possessed by each of their constituent members. M. Izolet considers society as an organism, which he calls a "hyperzoary." Herbert Spencer has developed the comparison of the collective organism with the individual organism, insisting on its resemblances and differences. Th. Ribot has dwelt especially on the resemblances.

The postulate that we have clearly stated here is understood as an axiom by many minds. But it is not an axiom. In saying that there is nothing in the complex that can not be found in the parts they think they are expressing a self-evident truth; they are, in fact, merely stating an hypothesis. That arrangement, aggregation, and complicated and skillful grouping of elements can produce nothing really new in the order of phenomena is an assertion that needs to be verified in each particular case.

The principle of continuity, a consequence of the preceding.—Let us apply this principle to organized beings. All beings in nature are actually arrangements, aggregates, or groupings of the same universal matter; that is to say, of the same simple chemical bodies. It results from the preceding postulate that their activities can differ only in degree and form, and not fundamentally. There is no essential difference of nature between the activities of various categories of beings, no heterogeneity, no discontinuity. We may pass from one to another, encountering no hiatus or impassable gulf. The law of continuity thus appears as a simple consequence of the fundamental postulate; and so is the law of evolution, for evolution is merely continuity in action.

Such are the origins of the philosophical doctrine which universalizes life and extends it to all bodies in nature.

It may be remarked that this doctrine is not confined to any particular school or sect. Leibnitz was not at all a materialist, and endowed his mundane elements, his monads, not only with a sort of life, but even with a sort of soul. Father Boscowich, though he was a Jesuit and a professor in the College of Rome, did not deny to his indivisible points a species of inferior vitality. St. Thomas, too, the angelical doctor, according to M. Gardair, accorded to inanimate substances a certain kind of activity, native inclinations, and a real appetition toward certain acts.

II.

ORIGIN OF BRUTE MATTER IN LIVING MATTER.

There should be two ways of proving the doctrine of the essential identity of brute matter and living matter—one slower and more laborious, the other more rapid and decisive.

Identification of the two matters, brute and living.—The laborious method, that which we shall be obliged to follow, consists in examining attentively the various activities by which life is manifested and

attempting to find more or less crude equivalents for them in brute bodies or in certain of them.

Decisive verification—Spontaneous generation.—The rapid and decisive method, which unhappily is beyond our resources, would consist in showing unquestionable, clearly marked life, the superior life, arising from the kind of inferior life that is attributed to matter in general. It would only be necessary to completely construct in all its parts, by a suitable combination of inorganic materials, a single living being, even the humblest plant or the most rudimentary animal. This would indeed be an irrefutable proof that the germs of all vital activity are contained in the molecular activity of brute bodies and that there is nothing essential to the latter that is not found in the former.

Unhappily this demonstration can not be given. Science furnishes no example of it, and we are forced to have recourse to the slow method.

The question here involved is that of spontaneous generation. It is well known that the ancients believed in spontaneous generation even for animals high in the scale of organization. According to Van Helmont, mice could be born by some incomprehensible fermentation in dirty linen mixed with wheat. Diodorus speaks of animal forms which were seen to emerge partly developed from the mud of the Nile. Aristotle believed in the spontaneous birth of certain fishes. Rejected as to the higher forms of animals, this belief was for a long time held with regard to the lower ones, such as bees, which the shepherd of Virgil saw coming out from the flanks of the dead bullock; such as flies engendered in putrefying meat; such as fruit worms and intestinal worms; finally with regard to infusoria and the most rudimentary vegetables. The hypothesis of spontaneous generation of the living being at the expense of the materials of the environment has been successively driven from one classificatory group to another. The history of the sciences of observation is also a history of the defeats of this doctrine. Pasteur gave it the finishing stroke when he showed that the simplest micro-organisms obeyed the general law which declares that a living being is formed only by filiation; that is to say, by the intervention of a preexisting living organism.

Spontaneous generation was an episode in the history of the globe.—Though we have been unable to effect spontaneous generation in the present time, it has been put back, by Haeckel, into a more or less distant past, to the moment when the cooling of the globe, the solidification of its crust, and the condensation of aqueous vapor upon its surface created conditions compatible with the existence of living beings similar to those with which we are acquainted. Lord Kelvin has fixed these geologic events as occurring from twenty to forty millions of years ago. Then circumstances became propitious for the appearance of the first organisms whence were successively derived those which now people the earth and the waters.

Circumstances favorable to the appearance of the first beings apparently occurred only in a far distant past, but the greater number of physiologists admit that if we knew exactly these circumstances and could reproduce them, we might also expect to produce their effect, which would be the creation of a living being, formed in all its parts, developed from the inorganic kingdom. For all those who think thus the impotence of experimentation at the present time is purely provisory. It is comparable to that of primitive men, before the time of Prometheus, who not knowing how to produce fire, could only get it by transmitting it from one to another. It depends upon the insufficiency of our knowledge and the weakness of our means; it does not establish the inherent impossibility of accomplishing the matter in question.

Contrary opinion—Life did not originate on our globe.—But all biologists do not share this view. Some, and not the least among them, hold it to be an established fact that it is impossible for life to arise from a concurrence of inorganic materials and forces. This was the opinion of the eminent botanist, Ferdinand Cohn; of the Saxon physician, H. Richter, and of W. Preyer, a physiologist well known from his noted researches in biological chemistry. According to these scientists life on the surface of the globe can not have been occasioned by reactions of brute matter and the forces that continue to dominate it.

According to F. Cohn and H. Richter life has had no beginning on our planet. It was transported to the earth from another world, or from the cosmic environment, under the form of cosmic germs, or *cosmozoans*, more or less comparable to the living cells with which we are acquainted. They may have made the journey either included in meteorites or floating in space in the form of cosmic dust. The doctrine in question has been presented under two forms, the hypothesis of meteoric cosmozoans, due to a French writer, the Count de Salles-Guyon, and that of cosmic panspermia, advanced in 1865 and 1872 by F. Cohn and H. Richter.

Hypothesis of the cosmozoans.—The hypothesis of the cosmozoans, living particles, protoplasmic germs emanating from other worlds and reaching the earth by means of stones falling from the sky, is due to a French writer, Count de Salles-Guyon. It is not so destitute of probability as one might at first suppose. Lord Kelvin and Helmholtz gave it the support of their high authority. Spectrum analysis shows in cometary nebulæ the four or five lines characteristic of hydrocarbons. Cosmic matter must then contain compounds of carbon, of the substances that are especially typical of organic chemistry. Besides, carbon and a sort of humus have been found in several meteorites. As to the objection that these aerolites are heated while passing through our atmosphere, Helmholtz responds that this elevation of temperature

may be quite superficial and allow micro-organisms to subsist in their interior. But other objections retain their force: First, that of M. Verworn, who considers the hypothesis of cosmic germs as inconsistent with the laws of evolution; then, that of L. Errera, who denies that the conditions necessary for life can exist in interplanetary bodies.

Hypothesis of cosmic pansperma.—Du Bois-Reymond has given the name of *cosmic pansperma* to a doctrine very similar to the preceding, formulated by H. Richter in 1865, and by F. Cohn in 1872. According to this, the first living germs arrived on our globe mingled with the cosmic dust that floats in space and falls slowly to the surface of the earth. If they escape by this gentle fall the dangerous heating of meteorites, L. Errera observes that they must remain exposed to the action of the luminous rays, which is generally destructive of germs.

Hypothesis of pyrozoans.—W. Preyer was not willing to accept this cosmic transmigration of even the most simple living beings, nor to bring other worlds into the history of our own. Life, according to him, must have subsisted for all time, even when the globe was an incandescent mass. But it was not the same life as at present. Vitality must have undergone many profound changes in the course of ages. The pyrozoans, the first living beings, vulcanians, were quite different from the beings of the present day that are disorganized by a slight elevation of temperature.

This theory of pyrozoans proposed by W. Preyer in 1872 certainly seems quite chimerical, and similar to the imaginings of Kepler, yet in a certain way it accords with contemporary ideas concerning the life of matter. It is related to them by the evolution which it implies in the materials of the terrestrial globe.

According to Preyer, primitive life existed in the fire. Being igneous masses in fusion the pyrozoans lived after their own manner; their vitality, slowly modified, finally took on the form which it presents to-day. Yet, in this profound transformation their number has not varied, and the total quantity of life in the universe has remained the same.

We recognize here the ideas of Buffon. These cosmozoans, these pyrozoans, have a singular resemblance to the organic molecules of "live matter" of the illustrious naturalist—everywhere distributed, indestructible, and forming, by their concentration, living structures.

But it is time to abandon scientific theories and to come to arguments based upon facts.

It is with a spirit quite different from that of the poets, the metaphysicians, and the more or less philosophical scientists that the science of our days looks at the obscure vitality of inanimate bodies. It thinks that there is to be recognized there, in a more or less rudimentary state, the action of the same factors which operate in living beings, the manifestation of the same fundamental properties.

III.

ORGANIZATION AND CHEMICAL COMPOSITION OF LIVING AND BRUTE MATTER.

Enumeration of the principal characters of living beings.—The programme which we have just sketched obliges us to seek in the brute being for the properties of living beings. What, then, are, in fact, the characteristics of an authentic, complete, living being? What are its fundamental properties? We have enumerated them above as follows: A certain chemical composition, which is that of living matter; a structure or organization; a specific form; an evolution which has a duration and an end, death; a property of growth or nutrition; a property of reproduction. Which of these characters counts for the most in the definition of life? If some of them were wanting, would that suffice to put back a being, who might possess the others, from the animate world to that of minerals? That is precisely the question that is under consideration.

Organization and chemical composition of living beings.—On the whole, all that we know concerning the constitution of living matter and its organization is contained in the laws of the chemical unity and morphologic unity of living beings. These laws seem to be a legitimate generalization from all the facts observed. The first declares that the phenomena of life are manifested only in and through living matter, protoplasm; that is to say, in and through a substance which has a certain chemical and physical composition. Chemically it is a proteid complexus with a hexonic nucleus. Physically it shows a frothy structure analogous to that resulting from the mixture of two granular, immiscible liquids differing in viscosity. The second law declares that the phenomena of life can only be maintained in a protoplasm which has the organization belonging to a complete cell, with its cell body and nucleus.

Relative value of these laws—Exceptions.—What is the signification of these laws of the chemical composition and organization of living beings? Evidently that life in all its plenitude can only occur and be perpetuated under their protection. If these laws were absolute, if it were true that no life were possible except in and through albuminous protoplasm, except in and through the cell, the problem of "the life of matter" would be decided in the negative.

May it not be, however, that fragmentary and incomplete vital manifestations, progressive sketches of a true life, may occur under different conditions; for example, in matter which is not protoplasm, and in a body which has a structure differing from that of a cell—that is to say, in a being which would be neither animal nor plant? This is the very question we have to consider, and we must seek its solution by the way of experimentation.

Without leaving the animal and vegetable kingdoms that is to say, among veritable living beings—we already perceive attenuation in the rigor of the laws governing chemical constitution and cellular organization.

The experiments of merotomy, that is to say of amputation, tried by Waller on nerves, on infusoria by Brandt, Gruber, Nussbaum, Balbiani, and Verworn, teach us the necessity of the presence of the cellular body and the nucleus—that is to say, of the integrity of the cell. But they also teach us that when that integrity no longer exists death does not immediately ensue. A part of the vital functions continues to be performed in denucleated protoplasm, in a cell which is mutilated and incomplete.

Vital phenomena in crushed protoplasm.—It is true also that grinding and crushing suppress the greater part of the functions of the cell. But tests with pulps of various organs and with those of certain yeast plants show that protoplasm, even though ground and disorganized, can not be considered as inert, and that it still exhibits many of its characteristic phenomena; for example, the production of diastases, specific agents of vital chemistry. Finally, while we do not know enough about the actions of which the secondary elements of protoplasm are capable—its granulations, its filaments, which one or another method of destruction might disclose—to be able to deny that protoplasm has power of action independent of its own integrity, we at least know that actions of this kind exist.

To summarize, we are far from being able to deny that rudimentary, isolated, vital acts may not be executed by the various bodies that result from the dismemberment of protoplasm. The integrity of the cellular organization, even the integrity of protoplasm itself, is not indispensable for these manifestations of vitality.

Besides, naturalists admit that within the protoplasm are aliquot parts, elements of an inferior order, which possess special activities. These secondary elements must have the principle of their activity within themselves. Such are the biophores to which Weissmann attributes the vital functions of the cell, nutrition, growth, and multiplication. If there are biophores within the cell they may be imagined as outside of it, and since they carry within themselves the principle of their activity, they may exercise it in an independent manner. Unhappily the biophores, and other elements of that kind, are purely hypothetical. They are like the gemmules of Darwin, the bioblasts of Altmann, and the pangenes of De Vries. They have no relation to facts of observation and to real existence.

Vital phenomena in brute bodies.—There is no doubt but certain phenomena of vitality may occur outside of the cell and its neighborhood. To carry this farther we may admit that they may be produced in certain unorganized bodies, in certain brute bodies. In every case there are surely produced effects similar at least to those which are

characteristic of living matter. It is for observation and experiment to decide as to the degree of similarity, and they have, in fact, decided that the similarity is complete. The crystals and crystalline germs studied by Ostwald and Tammann are the seat of phenomena quite comparable to those of vitality.

IV.

EVOLUTION AND MUTABILITY OF LIVING MATTER AND BRUTE MATTER.

One of the most remarkable characteristics of a living being is its evolution. It undergoes a continuous change. It starts with a feeble beginning; it is formed, grows, then in ordinary cases declines and disappears, having followed a predictable course, regulated as to time, a sort of ideal trajectory.

Supposed immobility of brute bodies.—It may be asked whether this evolution, this directed mobility, is so exclusively a feature of the living being as it appears, and if many brute bodies do not present something analogous to it. The response is not at all doubtful.

Bichat was mistaken when he contrasted in this respect brute bodies with living bodies. Vital properties, he said, are temporary; it is their nature to exhaust themselves; in time they are used up in the same body. Physical properties, on the contrary, are eternal. Brute bodies have neither commencement nor necessary end, neither age nor evolution; they remain as immutable as death of which they are the image.

Mobility and mutability of the sidereal world.—This is not true, in the first place, of the sidereal bodies. The ancients believed that the sidereal world was immutable and incorruptible. The doctrine of the incorruptibility of the heavens prevailed up to the seventeenth century. The observers who at that epoch directed toward the heavens the first telescope, which Galileo had just invented, were struck with astonishment at discovering change in the celestial firmament that they had believed incorruptible and by perceiving a new star that appeared in the constellation of Serpentarius. Such changes no longer surprise us. The cosmogonic system of Laplace has become familiar to all cultivated minds and everyone is accustomed to the idea of the mobility and continual evolution of the celestial world. "The stars have not always existed," writes M. Faye; "they have had a period of formation; they will likewise have a period of decline, followed by a final extinction."

All the bodies of inanimate nature are not, then, eternal and immutable; the celestial bodies are eminently susceptible of evolution, slow indeed compared with that we observe on the surface of our globe; but that disproportion, corresponding to the immensity of time and of cosmic spaces as compared with our terrestrial measurements, should not mislead us as to the fundamental analogy of the phenomena.

I. THE MOVEMENT OF PARTICLES AND MOLECULES IN BRUTE BODIES.

It is not only in the celestial spaces that we must search for that mobility of brute matter that imitates that of living matter. In order to find it we have only to look about us or to interrogate physicists and chemists.

As to the geologists, M. le Dantec speaks somewhere of one of them who divided minerals into living rocks, those susceptible of changing their structure, of undergoing an evolution under the influence of atmospheric causes; and dead rocks, those which, like clay, have found at the end of all their changes a final state of repose. Jerome Cardan, a celebrated scientist of the sixteenth century, at once mathematician, naturalist, and physician, declared not only that stones live, but that they suffer from disease, old age, and death. The jewelers of to-day speak in this way concerning certain precious stones, turquoises, for example.

The alchemists carried these ideas to an extreme. It is not necessary here to recall the past, to evoke hermetic beliefs or the dreams of the alchemists, according to whom the different kinds of matter lived, developed, and were transmuted into each other.

We refer to precise and recent data, established by the most expert investigators, and related by one of them, Ch. Ed. Guillaume, three years ago, before the Helvetic Society of Natural Sciences. These data show that the determinate forms of matter may live and die, in the sense that they may become modified in a slow and continuous manner, always in the same direction, until they have attained an ultimate and definite state which is that of eternal repose.

The intestinal movements of bodies.—The reply of Swift to an idle fellow who spoke slightingly of work is well known: "In England," said the author of Gulliver, "men work, women work, horses work, oxen work, fire works, and beer works; there is only the pig who does nothing at all; he must be, therefore, the only gentleman in England." We know very well that English gentlemen also work. Indeed, everybody and everything works. And the celebrated humorist was nearer right than he supposed in comparing in this respect men and things. Everything is at work; everything in nature toils and strives, at every stage, in every degree. Immobility, repose, are usually, in natural things, merely a false appearance; the seeming quietude of matter is caused by our inability to appreciate its interior agitation. Because of their minuteness we do not perceive the swarming particles that compose it, and which, under the impassable surface of bodies, oscillate, displace each other, move to and fro, and group themselves into forms and positions adapted to the conditions of the environment. In comparison with these microscopic elements we are like the giant of Swift in the midst of the people of Lilliput; and this is far below the actual facts.

Kinetic conception of molecular movements.—The idea of this peculiar agitation is by no means new to us. We were familiarized with it in scientific theories during our college days. The atomic theory teaches us that matter behaves, from a chemical point of view, as if it were divided into molecules and atoms. The kinetic theory explains the constitution of gases and the effects of heat by supposing that these particles are endowed with movements of rotation and displacement. The wave theory explains luminous phenomena by supposing peculiar vibratory movements in a special medium, the ether. But these are merely hypotheses which are not at all necessary; they are the images of things, not the things themselves.

Reality of the movements of particles. Here there is no question of hypotheses. This intestinal agitation, this interior work, this incessant activity of matter are positive facts, an objective reality. It is true that when the chemical or mechanical equilibrium of bodies is disturbed it is restored more or less slowly. Sometimes days and years are required before it is regained. Scarcely do they attain this relative repose when they are again disturbed, for the environment itself is not fixed; it suffers variations which react in their turn upon the body under consideration; and it is only at the end of these variations, at the end of their respective periods, that they together attain, in a universal uniformity, an eternal repose.

We shall see that metallic alloys undergo continual physical and chemical changes. They are always seeking an equilibrium which more or less escapes them. Physicists in modern times have given their attention to this intestinal activity of material bodies in pursuit of stability. Wiedemann, Warburg, Tomlinson, MM. Duguet, Brillouin, Duhem, and Bouasse have revived the old experimental studies of Coulomb and Wertheim upon the elasticity of bodies, the effects of pressure, traction, hammering of metals, tempering, and annealing.

The intestinal activity manifested under these circumstances presents quite remarkable characteristics which have been almost necessarily compared to the analogous phenomena presented by living bodies. There has been created, even in physics, a figurative terminology, and metaphorical expressions have been borrowed from biology.

Comparison of the activity of particles with vital activity.—It was Lord Kelvin who first spoke of the fatigue of metals, or the fatigue of elasticity, and, since then, Bose showed for these same bodies the fatigue of the electric touch [tact électrique]. The term accommodation has been employed in the study of torsion, and according to Tomlinson, for precisely those phenomena which are the inverse of those of fatigue. The phenomena presented by glass when it is subjected to an exterior force which slowly bends it, have been considered as those of adaptation. The methods by which a bar of steel resists wire-drawing have been regarded as means of defense against threatened rupture. And

M. Charles Edward Guillaume speaks somewhere of "the heroic resistance of the bar of nickel-steel." The term "defense" has been also applied to the behavior of chloride or iodide of silver when exposed to light.

There has been no hesitation in using the term "memory" concurrently with that of hysteresis to designate the behavior of bodies submitted to the action of magnetism or of certain mechanical forces. It is true that M. H. Bouasse protests in the name of the physico-mathematicians against the employment of these figurative expressions. But has he not himself written "a twisted wire is a watch wound up," and elsewhere "the properties of bodies depend at every moment upon all anterior modifications?" Is this not to say that they retain in some manner the impression of the changes they have experienced? Powerful deformative agencies leave a trace of their action, they modify the state of molecular aggregation of the body, and some physicists go so far as to say that they even modify its chemical constitution. With the exception of M. Duhem, the mechanicians who have studied elasticity admit that the effect of an exterior force upon a body depends upon the forces to which it has been previously subjected, and not merely upon those which are acting upon it at the time. Its present state can not be predetermined, it is the recapitulation of preceding states. The effect of a torsional force upon a new wire will be different from that of the same force upon a wire previously subjected to torsions and detorsions. It was with reference to actions of this kind that Boltzmann in 1876 declared that a wire that has been twisted or drawn out remembers for a certain time the deformations to which it has been subjected. This memory is defaced and lost after a certain definite period. Here then, in a problem of static equilibrium, there is introduced an unexpected factor—time.

To summarize, it is the physicists themselves who have indicated the correspondence between the state of existence in many brute bodies and that in many living bodies. It can not be expected that these analogies will in any way serve as explanations. We should rather seek the derivation of the vital phenomenon from the physical phenomenon. This is the sole ambition of the physiologist, and the inverse of this would be unreasonable. We do not assume to do this here. It is nevertheless true that analogies are of service, were it only to shake the confidence which, since the time of Aristotle, has been accorded to the division of the bodies of nature into *psuchia* and *apsuchia*, that is to say, into living and brute bodies.

2. THE BROWNIAN MOVEMENT.

The existence of the Brownian movement.—The most simple means of judging of the working activities of matter is to observe it in the case where the liberty of the particles is not interfered with by the

action of the neighboring particles. We approach that condition when we observe through the microscope grains of dust suspended in a liquid or globules of oil suspended in water. Now the result of this case is well known to all microscopists. If the granulations are sufficiently small, they are seen to be never at rest. They are animated by a sort of incessant tremor; we see the phenomenon called the "Brownian movement." The spectacle of this agitation has struck all observers since the invention of the loupe or simple microscope. But the Englishman, Brown, in 1827, made it the object of a special study and left it his name. The exact explanation of it remained for a long time obscure. It was given in 1894 by the learned physicist of the faculty of Lyons, M. Gouy.

The observer who for the first time looks through the microscope at a drop of water from the river, from the sea, or from any ordinary source—that is to say, water not specially purified—is struck with surprise and admiration at the spectacle of the motion that appears in it. Infusoria, microscopic articulata, various micro-organisms, people the microscopic field and animate it with their movements; but at the same time all sorts of particles are also agitated, particles which can not be considered as living beings and which are, in fact, nothing but organic detritus, mineral dust and débris of every description. Quite often the singular movements of these granulations, which simulate up to a certain point those of living beings, have perplexed the observer or drawn him into error, and the bodies that manifest them have been taken for animalcules or for bacteria.

Characters of this movement.—But it is ordinarily quite easy to avoid this confusion. The Brownian movement is a sort of oscillation, a treadmill of to and fro movement not accompanied by translation. It is a Saint Guy's dance executed in one spot, thus distinguished from the movements of displacement habitual to animate beings. Each particle executes its own special dance. Each one acts on its own account independently of its neighbor. There is, however, in the execution of these individual oscillations a sort of common and regular character which arises from the fact that their amplitudes differ little from each other. The largest particles are the slowest; above four one-thousandths of a millimeter in diameter they almost cease to be mobile. The smallest are most active. When so small as to be barely visible through the microscope the movement is extremely rapid and can only occasionally be perceived. It is probable that it would be still more accelerated for smaller objects, but the latter are destined to eternally escape our observation.

Its independence of the nature of the bodies and of the environment.—M. Gouy has remarked that the movement depends neither on the nature nor on the form of the particles. Even the nature of the liquid has but little influence. Its degree of viscosity alone is of effect.

The movements are, indeed, more lively in alcohol or ether, which are very mobile liquids. They are slow in sulphuric acid and glycerin. In water, a grain one two-thousandth of a millimeter in diameter traverses, in a second, ten or twelve times its own length.

The fact that the Brownian movement is seen in liquors which have been boiled, in acids and in concentrated alkalis, in toxic solutions of all degrees of temperature, shows conclusively that the phenomenon has no vital significance; that it is in no way connected with vital activity so called.

Its indefinite duration.—The most remarkable character of this phenomenon is its permanence, its indefinite duration. The movement never ceases, the particle never arrives at repose and equilibrium. Granitic rocks contain quartz crystals which at the moment of their formation included within a closed cavity a drop of water which contained a bubble of gas. These bubbles, contemporary with the Plutonian age of the globe, have never from that time ceased to manifest the Brownian movement.

Its independence of external conditions.—What is the cause of this eternal oscillation? Is it a tremor of the earth? No. M. Gouy saw the Brownian movement exist far from cities, where the mercurial mirror of a seismograph showed no subterranean vibration. It did not increase when these vibrations appeared and became quite appreciable. Neither is it changed by variation in light, magnetism, or electric influences; in a word, by external occurrences. The result of observation is to place before us the paradox of a phenomenon which is kept up and indefinitely perpetuated in the interior of a body without known exterior cause.

The Brownian movement must be the first stage of molecular movement.—When we take in our hands a sheet of quartz which contains a gaseous inclusion we seem to be holding a perfectly inert object. When we have placed it upon the stage of the microscope and have demonstrated the agitation of the bubble we are convinced that this seeming inertia is merely an illusion.

The repose exists only in the limitations of our vision. We see the objects as we see from afar a crowd of people; we perceive them as a whole, without being able to discern the individuals or their movements. A visible object is, in the same way, a mass of particles. It is a molecular crowd. It gives us the impression of an indivisible mass, of a block in repose; but as soon as a lens brings us near to this crowd, as soon as the microscope enlarges for us the minute elements of the brute body, then it appears to us, and we perceive the continual agitation of those who are at least four one-thousandths of a millimeter in diameter. The smaller the particles under consideration, the more lively are their movements. From this we infer that if we could perceive molecules whose probable dimensions are about one thousand

times less, their probable velocity would be, as required by the kinetic theory, some hundreds of millimeters per second. The Brownian velocity of the smallest objects we can perceive is but some thousandths of a millimeter per second. Doubtless, concludes M. Gouy, the particles that show this movement are really enormous when compared with true molecules. Looked at in this way, the Brownian movement is but the first degree and a gross manifestation of the molecular vibrations which the kinetic theory supposes.

3. THE INTESTINAL ACTIVITY OF BODIES.

Migration of material particles.—In the Brownian movement we take into account only very small, isolated masses, small free fragments: that is to say, material particles which are not hampered by their relations to neighboring particles. Any other but a physicist might believe that in true solids endowed with cohesion and tenacity in which the molecules are bound one to the other, in which the form and the volume are fixed, there could be no longer any movements or changes. This is an error. Physics teaches us the contrary, and, especially in these latter years, has furnished us characteristic examples. There are veritable migrations of material particles throughout solid bodies—migrations of considerable extent. They are accomplished through the agency of diverse forces acting from the exterior—pressures, tractions, torsions—sometimes under the action of light, sometimes under the action of electricity, sometimes under the influence of forces of diffusion. The microscopic observation of alloys by MM. H. and A. Lechâtelier, J. Hopkinson, Osmond, Charpy, J.-R. Benoit; the studies of their physical and chemical properties by MM. Calvert, Matthiessen, Riche, Roberts Austen, Lodge, Laurie, and Ch.-Ed. Guillaume; the experiments in the electrolysis of glass, and the curious results of Bose upon the electric touch [tact-électrique] of metals show in a striking manner the chemical and kinetic evolutions which occur in the interior of bodies.

Migration under the influence of weight.—An experiment of Obermeyer which dates from 1877 furnishes a good example of the migrations of solid bodies through a hardened viscid mass under the influence of weight. Shoemaker's wax, the black wax that shoemakers and boat builders use, is a kind of resin extracted from the pine and other resinous trees, melted in water, and separated from a more fluid part which rises above it. It is colored by the lampblack produced by the combustion of straw and fragments of bark. At an ordinary temperature it is a mass so hard that it can not always be indented easily by the finger nail; but if it is left to itself in a receptacle it finally yields, spreads out as if it were a liquid, and conforms to the shape of the vessel. Suppose we place within a cavity hollowed out of a piece of wood a portion of this wax and keep it there by means of a few peb-

bles, having previously placed at the bottom of the cavity some fragments of a light substance, like cork. The piece of wax is thus between a light body below and a heavy body above. If we wait a few days this order is reversed - the wax has filled the cavity by conforming to it; the cork has passed through the wax and appears upon the surface, while the stones are at the bottom. We have here the celebrated experiment of the flask with the three elements, in which are seen the liquids mercury, oil, and water superposed in the order of their density, demonstrated in this case by means of solid bodies.

Influence of diffusion. -Diffusion, which disseminates liquids throughout each other, may also cause solids to pass through other solids. W. Roberts Austen places a little cylinder of lead upon a disk of gold and keeps the whole at the temperature of boiling water. At this temperature both metals are perfectly solid, since gold does not melt up to 1,200° C. nor lead up to 330°. Still, after this contact has been prolonged for a month and a half, analysis shows that the gold has become diffused to the top of the cylinder of lead.

Influence of electrolysis.—Electrolysis offers another means of transportation no less remarkable. By its means we may force metals, such as sodium or lithium, to pass through glass walls. The experiment may be performed in the method indicated by M. Charles Guillaume. A glass bulb containing mercury is placed in a bath of sodium amalgam and a current is then made to pass from within outward. After some time it can be shown that the metal has penetrated the wall of the bulb and become dissolved in the interior.

Influence of mechanical pressure.—Mechanical pressure is also capable of causing one metal to pass into another. We need not recall the well-known experiment of Cailletet, who, by employing considerable pressure, caused mercury to sweat through a block of iron. In a more simple manner W. Spring showed that a disk of copper could be welded to a disk of tin by pressing them strongly one against the other. There is formed, up to a certain distance from the surfaces of contact, a veritable alloy; there is a layer of bronze of a certain thickness which unites the two metals, and this could not take place did not the particles of both metals mutually interpenetrate.

4. INTESTINAL ACTIVITY OF ALLOYS.

Structure of alloys.—Metallic alloys have a remarkable structure which is essentially mobile and which we have now begun to understand, thanks to the employment of the microscope. Microscopical examination justifies to a certain degree the supposition of Coulomb. That illustrious physicist explained the physical properties of metals by imagining that they were formed of two kinds of elements—integral particles, to which the metal owes its properties of elasticity, and a cement which binds the particles and to which it owes its coherence.

M. Brillouin has again taken up this hypothesis of duality of structure. The metal is supposed to be formed of very small, isolated, crystalline grains embedded in an almost continuous network of viscous matter; a more or less compact mass surrounding more or less distinct crystals is the conception which may be formed of an alloy.

Changes of structure produced by deforming agencies.—It has been shown that profound changes of crystalline structure can be produced by various mechanical means, such as hammering and the traction of metallic bars carried as far as rupture. Some of these changes are very slow, and it is only after months and years that they are completed and the metal attains the definitive equilibrium corresponding to the conditions in which it is placed. Though there may be discussions concerning the nature of the transformations to which it is subjected, though some believe they affect the chemical condition of the alloy, while others limit its power to physical effects, it is nevertheless true—and this brings us back to our subject—that the mass of these metals is at work and that it only slowly attains the phase of complete repose.

The slow reestablishment of equilibrium—Residual effect.—These operations by which the physical characters of metals are changed, and by which they are adapted to a variety of industrial needs—compression, hammering, rolling, traction, and torsion—have an immediate, very apparent effect; but they have also a consecutive effect, slowly produced, much less marked and less evident. This is the residual effect or "Nachwirkung" of the Germans. It is not without importance even in practical applications.

Heat also creates a sort of forced equilibrium. This becomes but slowly modified, so that a body may remain for a long time in a state which is nevertheless the most stable for the conditions under which it is considered. The number of these bodies out of equilibrium is as great as that of the matters which have been submitted to fusion. All the Plutonian rocks are in this condition. Glass presents a similar one. Thermometers placed in melting ice do not always mark the zero of centigrade. This displacement of the zero point falsifies all their indications if care is not taken to correct it. This correction usually demands a long observation. The theory of the displacement of the thermometric zero is not entirely established, but we may suppose with the author of the Traité de Thermométrie that there exists in glass, as in alloys, compounds which vary according to the temperature. At each temperature glass tends to assume a determinate composition and a corresponding state of equilibrium, but the previous temperature to which it has been subjected has evidently an influence upon the rapidity with which it attains its state of repose. The effect of variation is more marked as we observe glasses of more complicated composition. We can readily understand that those which contain comparable quantities of the two alkalies, soda and potash, may be

more subject to these modifications than those having a more simple composition based on a single alkali.

Effects of annealing.—A piece of brass wire that has been drawn and then heated is the theatre of very remarkable internal changes that have been only recently recognized. The violence done to the metallic thread in forcing it through the hole in the die crushed the crystalline particles; the interior state of the wire is that of broken crystals surrounded by a granular mass. Heating changes all that. The crystals separate, repair themselves, and reform; they are then hard, geometrical bodies, plunged in an amorphous mass, relatively soft and plastic; their number keeps on increasing; equilibrium is not established until the entire mass is crystallized. One may imagine how many displacements, enormous when compared with their dimensions, the molecules have to undergo when transporting themselves throughout the resisting mass and arranging themselves in definite places in the crystalline edifices.

In the same way, too, in the manufacture of steel, the particles of coal at first applied to the surface traverse the iron.

This faculty of molecular displacement permits in some cases the metal to modify its state at one point or another. The use made of this faculty in certain circumstances is very curious, greatly resembling the adaptation of an animal to its environment, or the methods of defense which it employs to resist agents that might destroy it.

Effect of traction and striction—Experiment of Hartmann.—When a cylindrical rod of metal, held firmly at either end—a test rod, as it is called in metallurgy—is subjected to a powerful traction it often elongates considerably, part of the elongation disappearing as soon as the strain stops, another part remaining. The total elongation is thus the sum of an "elastic elongation," which is temporary, and a "permanent elongation." If we continue the traction there appears at some point of the rod a narrowing, a striction. It is there that the rod will break.

But in place of continuing the traction, Mr. Hartmann suspends it. He stops, as if to give the metal being time to rally. During this delay it would seem that the molecules hasten to the menaced point to reinforce and harden the weak part. In fact, the metal which was soft at other points has here taken on the aspect of tempered metal. It is no longer extensible.

When the experimenter recommences traction after this rest, the narrowed bar having been submitted to the action of a roller and returned to a cylindrical form, a second narrowing forms at another point. If another rest is given this striction also will become resistant.

If we renew this experiment a sufficient number of times there will result a total transformation of the rod, which will become hardened throughout its entire extent. It will break rather than elongate if the traction is sufficiently energetic.

Nickel steels—Their heroic defense.—Nickel steels present this phenomenon in an exaggerated degree. The alternation of operations which we have just described, which bring the various parts of an ordinary steel rod into a tempered state, is not necessary with nickel steel. The effect is produced in the course of a single trial. As soon as there is any narrowing at any point the alloy hardens at that precise place; the striction is hardly marked; the movement is stopped at this point to attack another feeble point, stops there again and attacks a third, and so on; and finally the paradoxical fact appears that a rod of metal which was in a soft state and could be considerably elongated has now become throughout its whole extent hard, fragile, and inextensible like tempered steel. It is in connection with this fact that M. Chas. Edward Guillaume spoke of heroic resistance to rupture. It would seem, in fact, as if the bar of nickel iron had reenforced each weak point in proportion as it was menaced. It is only at the end of these efforts that the inevitable catastrophe occurs.

Effect of temperature.—When the temperature changes it is seen that these nickel irons elongate or retract, modifying at the same time their chemical constitution. But these effects, like those which occur in the glass reservoir of a thermometer, are not acquired all at once. They are produced rapidly for one part and more slowly for a small remainder. Bars of nickel iron which have been kept at the same temperature change gradually in length during the course of an entire year. Can we find a better proof of intestinal activity occurring in a substance greatly differing from living matter?

Nature of the activity of particles.—These are examples of the intestinal activity that occurs in brute bodies. Besides, these facts that we are citing merely to refute the assertion of Bichat relative to the immutability of brute bodies and to show their activity bring us, in addition, another proof. They show that this activity, like that of animals, is a guard against foreign intervention, and that this guard, again like that of animals, is adapted for the defense and preservation of the brute mass.

If we accord a special value to the adaptative or teleological characteristic of vital phenomena, a characteristic which is so easily abused in biological interpretations, we may also find it again in the inanimate world. To this end we may add to the preceding examples a last one which is no less remarkable. This is the famous case of the photography of colors after Becquerel's method.

Photography of colors.—A grayish plate, treated with chloride or iodide of silver and exposed to a red light, rapidly becomes red. It is then exposed to green light and after passing through some dull and obscure tints it becomes green. If we wished to explain this remarkable phenomenon we could do no better than to say that the silver salt protects itself against the light that threatens its existence; that light

causes it to pass through all states of coloration before reducing it; the salt stops at the state which protects it best. It stops at red, if it is red light that assails it, because by becoming red it repels by reflection that light; that is to say, it absorbs it the least.

It may then be advantageous, for the purpose of comprehending natural phenomena, to regard the transformations of inanimate matter as manifestations of a sort of internal life.

Conclusion—Relations of the surrounding medium to the living being and the brute body.—Brute bodies then are not immutable any more than are living bodies. Both depend upon the medium that surrounds them, and they depend upon it in the same way. Life brings together, puts in conflict, an appropriate organism and a suitable environment. Auguste Comte and Claude Bernard have taught us that vital phenomena result from the reciprocal action of these two factors which are in close correlation. It is also from the reciprocal action of the environment and the brute body that inevitably result the phenomena which that body presents. The living body is sometimes more sensitive to ambient variations than is the brute body, but at other times the reverse is the case. For example, there is no living organism as impressionable to any excitant whatever as is the bolometer to the slightest variations of temperature.

There can only be, then, one chemically immutable body, which is the atom of a simple body, since according to its very definition it remains unaltered and unalterable in combinations. This notion of an unalterable atom has, however, itself been attacked by the doctrine of the ionisation of particles advanced by J. J. Thomson; and besides, with very few exceptions—those of cadmium, mercury, and the gases of the argon series—the atoms of simple bodies can not exist in a free state.

So it is that, as in the vital struggle, the ambient medium furnishes to the living being, in whole or in part by alimentation, the materials of its organization and the energies which it puts in play. It also furnishes to brute bodies their materials and their energies.

It is also said that the ambient medium furnishes the living being a third class of things, the stimulants of its activities—that is to say, its "provocation to action." The protozoan finds in the aquatic environment which is its habitat the stimulants which provoke it to move and to absorb its aliments. The cells of the metozoan encounter in the same way in the lymph, the blood, and the interstitial liquids which bathe them the shock, the excitation which brings their energies into play. They do not have in themselves, by a mysterious spontaneity without example in the rest of nature, the capricious principle which sets them in motion.

Vital spontaneity, so readily admitted by persons ignorant of biology, is disproved by all the history of the science. Every vital manifesta-

tion is a response to a stimulation, a provoked phenomenon. It is not necessary to say that it is the same with brute bodies, since that is precisely in what consists the great principle of the inertia of matter. It is plain that it is also as applicable to living as to inanimate matter.

V.

SPECIFIC FORM. LIVING BODIES AND CRYSTALS.

1. SPECIFIC FORM AND CHEMICAL CONSTITUTION.

In the enumeration which we have made of the essential features of vitality there are three that have, so to speak, a prime value. These are, in the order of their importance: The possession of a specific form; the faculty of growth, or nutrition; and finally, the faculty of reproduction by generation. By restricting our comparison between brute bodies and living bodies to these truly fundamental characters we restrict the field, but we shall see that the resemblances do not disappear.

Wide distribution of crystalline forms.—In the mineral world we have only to consider crystallized bodies, they being almost the only ones that possess definite form. In restricting ourselves to this category we do not limit our field so much as might be supposed. Crystalline forms are widely distributed. They are, in a manner, universal. Matter has a decided tendency to assume these forms whenever the physical forces which it obeys act with order and regularity and their action is not disturbed by accidental occurrences. In the same way, too, living forms are only possible in regulated environments, under normal conditions, protected from cataclysms and convulsions of nature.

The possession of a specific form is the most significant feature of an organized being. Its tendency, from the time it begins to develop from the germ, is toward the acquirement of that form. The progressive manner in which it seeks to realize its architectural plan in spite of the obstacles and difficulties that arise—healing its wounds, repairing its mutilations—all this, in the eyes of the philosophical naturalist, forms what is perhaps the most striking characteristic of a living being, that which best shows its unity and its individuality. This property of organogenesis seems preeminently a vital property. It is not so, however, for crystalline bodies possess it in an almost equal degree.

The parallel between the crystal and a living being has been often drawn. We will not reproduce it here in detail. We wish only, after having sketched its principal features, to call attention to the new matters concerning it that have been brought out by recent investigations.

Organization of crystals.—Views of Haüy, Delafosse and Bravais, and of Wallerant.—In botany, zoology, and crystallography we understand by form an assemblage of material constituents coordinated in a definite system; that is to say, it is organization itself. The body of man, for example, is an edifice in which 60 trillions of cells ought each to find its own place fixed in advance.

In crystallography also we understand by form the organization which crystals present. The grouping of the elements of crystals is, perhaps, more simple. They are none the less organized, in the same sense that living bodies are.

Their organization, while more uniform than that of living bodies, still shows a considerable amount of variation. It should not be assumed that the area of a crystal is completely filled with contiguous parts applied one to the other by plane faces, as might be supposed from the phenomena of cleavage which dissociates the parts of the crystalline body into solids of this kind. In reality the constituent parts are separated from each other by spaces. They are arranged in quincunx, as Haüy says, or along the lines of a network, to use the terms of Delafosse and Bravais. The intervals left between them are much larger than their diameters. So it is that in the organization of a crystal it is necessary to take into account two quite different things: An element, the crystalline particle, which is a certain aggregate of chemical molecules having a determinate geometrical form, and a more or less regular, parallelopipedic network, along whose crests are arranged in a constant and definite manner the aforesaid particles. The external form of the crystal indicates the existence of the network. Its optical properties depend upon the action of the particles, as M. Wallerant has shown. There are, therefore, to be distinguished in a crystal two kinds of geometrical figures—that of the network and that of the particle—and their characters of symmetry may be either concordant or discordant.

The crystalline particle, the element of the crystal, is then a certain molecular complex that repeats itself identically and is identically placed at the nodes of the parallelopipedic network. It has been given different names well calculated to produce confusion—the crystallographic molecule of Mallard, the complex particle of other authors. Some have separated this element into subordinate elements (the fundamental particles of Wallerant and of Lapparent).

These very general outlines will suffice to show how complex and adjustable is the organization of the crystalline individual, which, in spite of its geometric regularity and its rigidity, may be compared with the still more flexible organization of the living element. The mineral individual is more stable, less prone to undergo change than is the living individual. We may say with M. Lapparent that "crystallized matter presents the most perfect and stable orderly arrangement of which the particles of bodies are susceptible."

Law of relation of specific form to chemical constitution. Crystallization is a method of acquiring specific form. The geometric architecture of the mineral individual is but little less than marvelous and no less characteristic than that of the living individual. Its form is the result of the mutual reactions of its substance and of the medium in which it is produced; it is the condition of material equilibrium corresponding to a given situation.

This idea of a specific form that belongs to a given substance under given conditions should be retained. We may consider it as a sort of principle of nature, an elementary law, which may serve as a point of departure for the explanation of phenomena. A particular substance, under identical conditions of environment, must always assume a certain form. This close linking of substance to form, admitted as a postulate in physical sciences, has been carried by some philosophical naturalists, such as M. Le Dantec, into the biological field.

Let us imitate them for a moment. Let us cease to seek in the living being for the prototype of the crystal; let us on the contrary seek in the crystal the prototype of the living being. If we succeed in this, we shall then have obtained a physical basis for life. Let us say, then, with the biologists of whom we have been speaking, that the substance of each living individual is peculiar to it; that it is specific, and that its form—that is to say its organization—follows from it. The morphology of any being whatever, of an animal—of a setter dog, for example—or even of a determinate being—of Peter, of Paul—is the "crystalline form of its living matter." It is the only form of equilibrium that can be assumed under the given conditions by the substance of the setter dog, of Peter or of Paul, just as the cube or the hopper form is the crystalline form of sea salt. In this manner these biologists have supposed that they could carry back the problem of living form to the problem of living substance and at the same time throw back the biological mystery upon the physical mystery.

Value of form as a characteristic of living and brute beings.—However this may be, it can be affirmed without fear of exaggeration, that the crystalline form characterizes the mineral with no less precision than the anatomical form characterizes the animal and the plant. In these two cases form—considered as a method of distribution of the parts—signalizes the individual and allows us to diagnose it with more or less facility.

Parentage of living beings and mineral parentage.—Still another analogy has been noted. In animals and plants similarity in form indicates similarity in descent, community of origin, and proximity in any scheme of classification. In the same way identity of crystalline form indicates mineral relationship. Substances chemically analogous show identical, geometrically superposable forms, and are thus arranged in family or generic groups recognizable at the first glance.

Isomorphism and the faculty of crossing.—Besides, the possibility, in the case of isomorphous bodies, of replacing each other in the same crystal during the process of formation and of thus mingling, so to speak, their congenital elements, may be compared with the possibility of interbreeding with living beings of the same species. Isomorphism is thus a kind of faculty of crossing. And as the impossibility of crossing is the touchstone of taxonomic relationship, as it is the proof of it, separating stocks that ought to be separated, so the operation of crystallization is also a means of separating from an accidental mixture of mineral species the pure forms which are there blended. Crystallization is the touchstone of the specific purity of minerals; and it is an important process in chemical purification.

Other analogies.—The analogies between crystalline and living forms have been pushed still further, even to the verge of abuse.

The internal and external symmetry of animals and plants has been compared to that of crystals. Transitions or intergradations have been sought between the rigid and faceted architecture of the latter and the flexible structure and curved surfaces of the former; the utricular form of sublimated sulphur on the one hand and the geometrical structure of the testa of radiolarians on the other are thought to show an exchange of typical forms between the two systems. An effort has even been made to draw a parallel between six of the principal main stems of the animal kingdom and the six crystalline systems. Pushed to this degree the proposition takes on a puerile character. Real analogies will suffice. Among these the curious facts of crystalline renewal deserve first place.

2. CICATRIZATION IN LIVING BEINGS AND IN CRYSTALS.

We know that living beings not only possess a typical architecture that they have themselves constructed, but that they defend it against destructive agencies and that at need they repair it. The living organism cicatrizes its wounds, repairs losses of substance, regenerates more or less perfectly the parts that have been removed; in other terms, when it has been mutilated it tends to reconstruct itself according to the laws of its own morphology. This phenomenon of reconstitution or redintegration, these more or less successful efforts to reestablish its form in its integrity, appear, at first sight, to be a characteristic feature of living beings. That is not the case.

Mutilation and redintegration of crystals.—Crystals—let us say crystalline individuals—show a similar aptitude for repairing their mutilations. Pasteur, in an early work, discussed these curious facts. Other experimenters, Gernez a little later and Rauber quite recently, took up the same subject and were only able to extend and confirm his observations. Crystals are formed from a primitive nucleus as the animal is formed from an egg; their integral particles are disposed

according to efficient geometrical laws so as to produce the typical form by a constructive process that may be compared to the embryogenic process that builds up the body of an animal. Now this operation may be disturbed by accidents in the surrounding medium or by the predetermined intervention of the experimenter. The crystal is then mutilated. Pasteur saw that these mutilations repaired themselves. "When," said he, "a crystal from which a piece has been broken off is replaced in the mother liquor, we see that while it increases in every direction by a deposit of crystalline particles, an excessive activity occurs at the place where it was broken or deformed; and in a few hours this suffices not only to build up the regular amount required for the increase of all parts of the crystal, but to reestablish regularity of form in the mutilated part." In other words, the work of formation of the crystal is carried on much more actively at the point of lesion than it would have been had there been no lesion. The same thing would have occurred with a living being.

Mechanism of the reparation.—Gernez some years later made known the mechanism of this reparation, or at least its immediate cause. He showed that on the injured surface the crystal becomes less soluble than on the other facets. This is not, however, an exceptional phenomenon. It is, on the contrary, quite frequently observed that the different faces of a crystal show marked differences in solubility. This is what occurs in every case for the mutilated face in comparison with the others; the matter is less soluble there. The consequence of this is evident; the growth must preponderate on that face, since there the mother liquor will become supersaturated before being so for the others. We may make this result understood in another way. Each face of the crystal in contact with the mother liquor is exposed to two antagonistic effects: The matter deposited upon a surface may be taken away and redissolved if, for any reason whatever, such matter becomes more soluble with reference to the liquid stratum in contact with it; in the second place, the matter of that liquid stratum may under contrary conditions be deposited and thus increase the body of the crystal. There is, then, for each point of the crystalline facet, a positive operation of deposit which results in a gain and a negative operation of redissolution which results in a loss. One or the other effect predominates according as the relative solubility is greater or less for the matter of the facet under consideration. On the mutilated surface it is diminished; deposition then prevails. But this is only the immediate cause of the phenomenon, and if we wish to know why the solubility has diminished on the mutilated surface M. Ostwald will explain it to us by showing that crystallization tends to form a polyhedron in which the surface energy is a minimum relative.

VI.

NUTRITION IN THE LIVING BEING AND IN THE CRYSTAL.

It has been said with justice that the property of nutrition may be considered as the most characteristic and essential one of living beings. Such beings are in a state of continual exchange with the surrounding medium. They assimilate and disassimilate. By assimilation the substance of their being increases at the expense of the surrounding alimentary material, which is rendered similar to that of the being itself.

Assimilation and growth in the crystal.—There exists in the crystal a property analogous to nutrition, a sort of nutrility, which is the rudiment of this fundamental property of living beings. The development of a crystal starts from a primitive nucleus, the germ of the crystalline individual that we will shortly compare to the ovum or embryo of a plant or an animal. Placed in a suitable culture medium—that is to say, in a solution of the substance—this germ goes on to develop. It assimilates the matter in solution, incorporates the particles of it, and increases, preserving at the same time its form, reproducing its specific type or a variety of it. Its growth proceeds without interruption. The crystalline individual may attain quite a large size if we know how to properly nourish it—we might say, to purvey to it. Very frequently, at a given time, a new particle of the crystal serves in its turn as a primitive nucleus, and becomes the point of departure for a new crystal engrafted upon the first.

Taken from its mother liquor, placed where it can not be nourished, the crystal, arrested in its growth, assumes a state of rest which is not without analogy with that of a seed or of a revivified animal. It awaits the return of favorable conditions, the bath of soluble matter, in order to resume its evolution.

The crystal is in a relation of continual exchange with the surrounding medium, which feeds it. These exchanges are regulated by the state of this medium, or, more exactly, by the state of the liquid stratum which is in immediate contact with the crystal. It loses or it gains in substance if, for example, that layer becomes heated or cooled more rapidly than it. In a general way it assimilates or disassimilates according as its environment is saturated or diluted. There is, then, in this a sort of mobile equilibrium, comparable, in some way, to that of the living being.

Methods of growth of the crystal and of the living being—intussusception—Apposition.—In truth, there seems to be a complete opposition between the crystal and the living being as regards their manner of nutrition and growth. The latter performs this by intussusception; the former by apposition. The crystalline individual is all surface. Its mass is impenetrable to the nutritive materials. Since only the

surface is accessible, the incorporation of similar particles is possible only by exterior juxtaposition, and the edifice increases only because a new layer of stones has been added to those which were there before. On the contrary, the body of an animal is a mass eminently penetrable. The cellular elements that compose it have forms that are more or less rounded and flexible. Their contact is by no means perfect. They do not have either the stiffness or the precision of adjustment that the crystalline particles have. Liquids and gases from without can insinuate themselves and circulate within the meshes of this loose construction. Assimilation can therefore take place throughout its whole depth, and the edifice increases because each stone increases by itself.

The secondary and commonplace character of the process of intussusception.—The apparent opposition of these two processes is doubtless diminished if we compare the simple mineral individual with the elementary living unit, the crystalline particle with the protoplasmic mass of a cell. Without carrying an analysis so far as this, it is yet easy to see that apposition and intussusception are mechanical means that living beings employ at one and the same time and combine according to their necessities. The hard parts of the interior and exterior skeleton increase, both by interposition and superposition at once. It is by the last method that bones increase in diameter, and that are formed the shells of mollusks, the scales of reptiles and fishes, and the testa of many radiate animals. In these organs, as in crystals, life and nutrition occur at the surface.

Apposition and intussusception are then secondary, mechanical arrangements having relation to the physical characters of these bodies: Solidity in the crystal, semifluidity in the cellular protoplasm. If we compare the inorganic liquid matter with the semifluid organized matter, we recognize that the addition of substance is made in the same manner in each, that is to say, by interposition. If we add a soluble salt to a fluid, the molecules of the salt separate and interpose themselves between those of the fluid. There is, therefore, nothing especially mysterious or particularly vital about the process of intussusception. Applied to fluid protoplasm it is merely the diffusion that ordinarily occurs in mixed liquids.

VII.

GENERATION IN BRUTE BODIES AND LIVING BODIES—SPONTANEOUS GENERATION.

We have not yet exhausted the analogies between a crystal and the living being. The possession of a specific form, the tendency to reestablish it by redintegration and the existence of a sort of nutrition do not suffice to constitute a complete similarity. It still lacks a fundamental character, that of generation. Chauffard, some time ago,

in an attack which he made upon the physiological ideas of that time, characterized the weakness of that point. "Let us disregard," he said, "those interesting facts relative to the acquisition of a typical form —facts that are common to the mineral world as well as to living beings. It is none the less true that the crystalline type is in no way derived from other preexisting types, and that nothing in crystallization recalls the actions of ascendants and the laws of heredity."

Since his time this gap has been filled. The works of Gernez, of Violet, of Lecoq de Boisbaudran, the experiments of Ostwald and of Tammann, the observations of Crookes and of Armstrong—all this series of researches, so well summarized by M. Leo Errera in his essays upon philosophical botany, had for their result the establishment of an unsuspected relation between the processes of crystallization and those of generation in animals and plants.

Protoplasm is a continuing substance—the case of the crystal.—Under the conditions of the present time a living being of any kind springs from another living being similar to itself.

Its protoplasm is always a continuation of the protoplasm of an ancestor. It is an atavic substance which we do not see begin, which we only see continue. The anatomical element comes from a preceding anatomical element, and the superior animal itself comes from a preexisting cell of the material organism, the egg. The ladder of filiation reaches back indefinitely into the past.

We shall see that there is something analogous to this in certain crystals. They are born from a preceding individual; they may be considered as the posterity of the antecedent crystal. If we speak of the matter of a crystal as the matter of a living being is spoken of in cases of this kind, we should be led to say that the crystalline substance is an atavic substance of which we see only the continuation, as occurs in the case of protoplasm.

Characteristics of generation in the living being.—Growth of the living substance, and consequently of the being itself, is the fundamental law of vitality. Generation is the necessary consequence of growth.

Living elements or cells can not subsist indefinitely without increasing and multiplying. There is certain to be a time when the cell divides, either directly or indirectly, and soon instead of one cell there are two. This is the method of generation for the anatomical element. In a complex individual it is a more or less restricted part of the organism, usually a simple sexual cell, that takes on the formation of the new being and consequently assures the perpetuity of the protoplasm and, through that, of the species.

Property of growth—Its supposed restriction to living beings.—At first it would appear that nothing like this occurs in inanimate nature. The physical machine, if we furnish it matter and energy, would seem to go on working indefinitely without being obliged to increase and

reproduce itself. There is, then, in this an entirely new condition peculiar to the organized being, a property well adapted, it would seem—and this time without any possible doubt—for separating living matter from brute matter. It is not so.

It would not be impossible to imagine a system of chemical bodies organized like the animal or vegetable economy, so that a destruction would be compensated for by a growth. What is impossible is to realize the supposition of M. le Dantec, a destruction that would at the same time be an analysis. And an additional perplexity occurs when he supposes that in the successive acts that have taken place exchanges of material may occur.

There is no necessity for making this impossible chemistry a characteristic of the living being. The chemistry of the living being is general chemistry. Berthelot repeated this after Lavoisier. These teachings of the masters should not be lost sight of by us.

Let us return to generation, properly so called, and find there the characteristics of brute bodies—of crystals.

The sowing of micro-organisms.—When a micro-biologist wishes to propagate a species of micro-organisms he charges a culture medium with a small number of individuals (one is all that is actually necessary) and soon observes their rapid multiplication. Usually, if only ordinary microbes that exist in atmospheric dust are wanted, the operator is not obliged to take the trouble of charging the culture; if the culture tube remains open and the medium is suitably chosen, some germ of a common species will fall in and the liquid will become colonized. This has the appearance of a spontaneous generation.

The sowing of crystals.—Concentrated solutions of various substances, supersaturated solutions of sulphate of soda, sulphate of magnesia, and chlorate of soda are also wonderful culture media for certain mineral organic units—certain crystalline germs. Ch. Dufour, experimenting with water cooled below 0° C., its point of solidification, Ostwald, with salol kept below 39.5°, its point of fusion, Tammann, with betol, which melts at 96°, and, before them, Gernez, with melted phosphorus and sulphur—all these physicists have shown that liquids in surfusion are also media specially appropriate for the culture and propagation of certain kinds of crystalline individuals.

Some of these facts have become classic. Löwitz showed in 1785 that a solution of sulphate of soda could be concentrated by evaporation so as to contain more salt than was conformable with the temperature, yet without depositing the excess. If, however, a solid fragment, a crystal of salt, was thrown into the liquor, that excess would soon pass into the state of a crystallized mass. The first crystal engendered a second similar to itself; the latter engendered a third, and so on from one to the other. If we compare this phenomenon with that of the rapid multiplication of a species of microbes in

a suitable culture medium, but one important difference will be perceived—the extreme rapidity of propagation of the crystalline germs as opposed to the relative slowness of the generation of the micro-organisms.

The crystalline individual gives birth, then, to another individual that conforms to its own type, or even to varieties of that type when such exist. Into the right branch of a U tube filled with sulphur in a state of surfusion Gernez dropped octahedric crystals of sulphur, and into the left branch prismatic crystals. On either side were produced new crystals conforming to the type that had been sown.

Sterilization of crystalline media and living media.—Ostwald varied these experiments with salol. He melted the substance by heating it above 39.5° C.; then, protecting it against any crystals, he let the solution stand in a closed tube. The salol remained liquid indefinitely—until it was touched with a platinum wire that had been in contact with solid salol; that is to say, until a crystalline germ was introduced. But if the platinum wire has been previously sterilized after the manner employed by bacteriologists, by passing it through a flame, it can then be introduced into the liquor with impunity.

The dimensions of crystalline germs are comparable to those of microbes.—We may dilute the solid salol with an inert powder—sugar of milk, for example—dilute the first mixture with a second, the second with a third, and so on; then, throwing into the solution of surfused salol a tenth of a milligram from one of these various mixtures, we find that the production of crystals will not take place if the fragment thrown in weighs less than a millionth of a milligram or measures less than ten thousandths of a millimeter on a side. It would seem, then, that these are the dimensions of the crystalline particle or crystallographic molecule of salol. In the same way Ostwald became assured that the crystalline germ of hyposulphite of soda weighs about a billionth of a milligram and measures a thousandth of a millimeter; that of chlorate of soda weighs a ten-millionth of a milligram. These dimensions are entirely comparable with those of microbes.

All these phenomena have been studied with a detail into which it is impossible to enter here, and which clearly shows more and more close analogies between the formation of crystals and the generation of micro-organisms.

Extension and propagation of crystallization—Optimum temperature of incubation.—Crystallization which has commenced around a germ is propagated more or less rapidly and ends by invading the entire liquor.

The rapidity of this movement of extension depends upon the conditions of the environment, particularly upon its temperature. This is shown very well by the experiments of Tammann with betol. This body, a salicylate of naphthyl, fuses at 96° C. If it is melted in tubes

sealed at a temperature of 100°, it may be cooled to lower and lower temperatures, to +70°, to +25°, to +10°, to −5°, without solidifying. Let us suppose that by some combination of circumstances a small number of centers of crystallization—that is to say, of crystalline germs—has appeared in the solution. Solidification will extend slowly at the ordinary temperatures of 20° to 25° and the neighborhood. On the other hand, it will be propagated with great rapidity if the liquor is kept at about 70°. This point, 70°, is the thermic optimum for the propagation of germs. It is the most favorable temperature for what might be called their incubation. As soon as the germs find themselves in a liquor at 70° they increase, multiply, and show that they are in the best conditions for growth.

Spontaneous generation of crystals—Optimum temperature for the appearance of germs.—If we consider various supersaturated solutions or liquids in surfusion, we shall soon discover that they can be arranged in two categories. Some remain indefinitely liquid under given conditions unless a crystalline germ is introduced into them. Others solidify spontaneously without artificial intervention; and such crystallization may even be propagated very rapidly under determinate conditions. These are for them conditions favoring the spontaneous appearance of germs.

This distinction between substances possessing crystalline generation by filiation and substances having crystalline generation that arises spontaneously is not specific. The same substance may present the two methods of generation according to the conditions in which it is placed. Betol furnishes a good example of this. Liquefy it at 100° in a sealed tube and keep it by means of a stove above 30°, and it will remain liquid almost indefinitely. On the other hand, lower its temperature and leave it for one or two minutes at 10° and germs will appear in the liquor; prolong the exposure to this degree of heat and the number of these spontaneously appearing germs will rapidly increase. On the other hand, you will observe that propagation by filiation, that is to say, by extension from one to another, is almost absent. The temperature of 10° is not favorable to that method of generation, and we have just seen, in fact, that it is at a temperature of about 70° that extension of crystallization from one to another is best accomplished. The temperature of 70° was the optimum for propagation by filiation. Inversely, the temperature of 10° is the optimum for spontaneous generation. Above and below this optimum the action is slower. We may count the centers of crystallization which slowly extend farther and farther, as in a microbic culture one counts the colonies corresponding to the germs primitively formed. To recapitulate, if there is an optimum for the formation of crystals there is also one, different from the first, for their rapid extension.

The metastable and labile zones.—This fact is general. There is for each substance a set of conditions (temperature, degree of concentration, volume of the solution) in which the crystalline individuals can be produced only by germs or by filiation. This is what occurs for betol above the temperature of 30 . The body is then in what Ostwald has called a *metastable zone*. There is, however, for the same body another set of circumstances more or less complex, in which its germs appear spontaneously. This is what happens for betol at about the temperature of 10°. These circumstances are those of the *labile zone* or of spontaneous generation.

Crystals of glycerin.—We may go a step further. Let us suppose, as does L. Errera, that we have a liquid that is found in a state of metastable equilibrium and whose labile equilibrium is yet unknown. This is what actually occurs for a very widely known body, glycerin. We do not know under what conditions glycerin crystallizes spontaneously. If we cool it, it becomes viscous; we can not obtain its crystals in that way. We did not even obtain its crystals in any way before the year 1867. In that year, in a tun sent from Vienna to London during winter, crystallized glycerin was found and Crookes showed these crystals to the Chemical Society of London. What circumstances had determined their formation? We were ignorant of them then and are still ignorant of them. It may be said that this case of spontaneous generation of the crystals of glycerin has not remained isolated. M. Henninger has noted the accidental formation of glycerin crystals in a manufactory of St. Denis.

It may be remarked that this crystalline species appeared, as living species may have done, at a given moment in an environment in which a favorable chance combined the conditions for its production. It is also quite comparable to the creation of a living species; for having once appeared, we have been able to perpetuate it. The crystalline individuals of 1867 have had a posterity. They have been sown in glycerin in a state of surfusion and there reproduced themselves. These generations have been sufficiently numerous to spread the species throughout a great part of Europe. M. Hoogewerf showed numerous examples of them filling a great flask to the Dutch naturalists who met at Utrecht in 1891. M. L. Errera presented others in June, 1899, to the Society of Medical and Natural Sciences at Brussels. To-day the great manufactory of Sarg & Co., of Vienna, engages in their production on a grand scale for industrial purposes.

We have been able to study this crystalline species of glycerin and to determine with precision the conditions which permit it to subsist. It has been shown that it does not resist a temperature of 18°, so that if precautions were not taken to preserve it, a single summer would suffice to annihilate all its crystalline individuals that exist on the surface of the globe, and thus extinguish the species.

Possible extinction of a crystalline species.—As these crystals melt at 18°, that temperature represents the point of fusion of solid glycerin or the point of solidification of liquid glycerin. Yet the liquor does not solidify at all if its temperature falls below 18°, nor does it solidify at zero, nor even at 18° below zero, it merely thickens and becomes pasty. We only know glycerin, then, in a state of surfusion, a fact which chemists have not learned without amazement.

With these conditions, so analogous to the appearance of a living species, to its unlimited propagation and to its extinction, the mineral world offers a quite faithful counterpart to the animal world. The living being illustrates here the history of the brute body and facilitates its exposition, and, inversely, the brute body in its turn throws a remarkable light on the subject of the living body and upon one of the most serious problems relative to its origin, that of spontaneous generation.

Conclusion.—These facts lead to a single conclusion. Up to the time when the concourse of propitious circumstances favorable to their spontaneous generation was brought about, crystals were obtained only by filiation. Up to the time of the discovery of electro-magnetism magnets were made only by filiation, by means of the simple or double application of a preexisting magnet. Before the discovery which fable attributes to Prometheus, every new fire was produced only by means of a spark derived from a preexisting fire. We are at the same historical stage as regards the living world, and it is for this reason that never up to this time has there been formed a single particle of living matter except by filiation, except by the intervention of a preexisting living organism.

THE CRANIOLOGY OF MAN AND ANTHROPOID APES.[a]

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[The Hunterian oration delivered on Thursday, February 14, 1901, at the Royal College of Surgeons of England.]

Gentlemen: We have assembled here to-day in order that we may commemorate the merits of John Hunter and such other persons whose labors have contributed to the extension of our knowledge in comparative anatomy, physiology, or surgery. Hunter's life, in all its various aspects, has been so frequently dwelt on in former orations delivered in this theater that it is beyond my power to throw any fresh light on this subject. His fame is attributable to his having possessed an intense love of science, indomitable energy, and a self-reliant, manly character. If we turn to his portrait hanging on the walls of this theater it would seem that at the time this likeness was painted Hunter was engaged in the study of the craniology of man and anthropoid apes, for on the table before him there is an open volume, and on its pages we see clearly drawn a human skull and the skull of a chimpanzee. Hunter is portrayed pen in hand, in deep thought, having just turned away from the book he had been studying; and though his notes on comparative anatomy were unfortunately destroyed with his

[a] Reprinted by permission from edition published by the author. London: Smith, Elder & Co., 1901.

[b] The chart [here made into several plates] accompanying the text of this oration was compiled from photographs of casts and of skulls in the museum of the Royal College of Surgeons of England. These photographs, with four exceptions, were taken by Mr. George in the photographic room on the college premises by kind permission of Prof. C. Stewart. The four exceptions include three photographs from skulls in the Thurnam collection, forming a part of the anatomical museum of the University of Cambridge, for which I have to thank Dr. J. Griffiths, and the fourth is a photograph of one of the Mentone skulls, for which I am indebted to A. J. Binny, esq. The other specimens shown on the chart were on the table, and were referred to during the oration. The portrait of John Hunter hanging on the wall of the theater belongs to the college, and was painted in the year 1785 by Sir Joshua Reynolds. The oration is published at the request of the council of the college.—N. C. Macnamara.

13 Grosvenor street W., March, 1901.

other manuscripts, we can hardly doubt that craniology was a subject in which he was deeply interested, or it would not have held so prominent a position in this famous picture. It would therefore seem that on an occasion such as the present we can do no higher honor to Hunter's memory, and to that of some of the able men of science who have followed him, than by endeavoring to give, in as few words as possible, a résumé of their labors, with especial reference to the subject of craniology and the light which it is capable of throwing on the prehistoric inhabitants of western Europe and of the evolution of the race of men to which we belong. One of the most brilliant and original thinkers who have occupied the presidential chair of this college, Sir William Lawrence, in his ever memorable lectures on the natural history of man, delivered in this college in the year 1819, from his researches in comparative anatomy foreshadowed the idea that man and apes were derived from common ancestors. Lawrence's opinions were received with a storm of adverse criticism. Mr. Abernethy, for instance, charged him with "propagating opinions detrimental to society, and endeavoring to enforce them for the purpose of loosening those restraints on which the welfare of mankind depend." Time, however, has proved that Lawrence was right, and in the course of lectures delivered in this theater in February, 1899, Professor Keith, from a careful analysis of the maximum number of anatomical characters common to man and apes, arrived at the conclusion that they are derived from an identical or a kindred stock. While admitting without reserve that man and apes are structurally almost identical, nevertheless, as pointed out by Professor Huxley in the year 1863, they differ very materially as regards the relative size and weight of their brains, as well as in the complexity of its convolutions. The carcass of a full-grown gorilla is heavier than that of an average-sized European, but it is doubtful whether a healthy adult European's brain ever weighed less than 32 ounces, or the brain of the heaviest gorilla ever exceeded 20 ounces in weight.[a] Although at the present time there is this marked relative difference between the weight of the brain and the form of the skulls of Europeans and apes, this was not always the case, for the calvaria of the earliest discovered human beings were in form not very far removed from those of contemporary anthropoid apes. This fact leads us to inquire into the nature of the conditions which have led to the increased capacity of the human cranium, and to the vast superiority of man's intellectual endowments over those of all the other primates. If we turn to Hunter's preparations in our museum[b] we find among them some remarkable specimens, which he describes as "compressed," "unsymmetrical" human crania, which he believed were the result of premature consolidation of one

[a] Man's Place in Nature, by Prof. T. Huxley, p. 103.
[b] College Catalogue, Nos. 135, 137, and 139.

or more of the sutures of the skull. Professor Virchow states that "in the too early ossification of a suture of the skull the development of the cranium is arrested in the diameter perpendicular to that center." Since Hunter's day various authorities have devoted much time to the subject of the abnormal closure of the cranial sutures in man. Prominent among them are the names of the chief of England's craniologists, Drs. Thurnam, Beddoe, and Barnard Davis (the splendid collection of prehistoric and other skulls made by the latter gentleman is now in the possession of our college), and we have come to learn that the size and shape of the skull depend, to a large extent, on the growth of the bones of which it is formed along the lines of the various cranial sutures, a subject to which I have referred at some length in my book on The Origin and Character of the British People.

It is well known that the frontal bone, which forms the vault of the anterior part of the cranium in the young of man and apes, is divided by a suture, and so long as this line of growth, together with the coronal and other sutures by which the frontal is separated from surrounding bones, remains open, the fore part of the skull, and with it the anterior fossæ which it incloses, can expand. But if the frontal and the other anterior sutures of the cranium consolidate early in life the fore part of the skull can not increase in capacity beyond the size it had reached in infancy. Professor Deneker[a] in his work on the embryology and development of anthropoid apes has shown that in consequence of the early closure of the anterior sutures of the skull of these animals the fore part of their brain does not increase beyond the size it had attained at the end of the first year of life; but in man these sutures do not consolidate until a much later period, so that the anterior lobes of his brain are enabled to expand, and actually become far more perfectly developed than the corresponding lobes among anthropoid apes.

Among these apes, in consequence of the great size of their frontal sinuses and the roofs of the orbits rising more obliquely into the cranial cavity, the anterior and the inferior walls of the anterior fossæ of their skulls intrude upon and lessen the capacity of this space, and therefore of the anterior lobes of the brain which are contained in these fossæ.[b] Virchow states that "of all parts of the ape's head, it is the brain that grows least;" even "the largest ape keeps its baby brain." Although we have not sufficient data to fix the absolute duration of the life of anthropoid apes, it is doubtful if they, as a rule, attain the age at which man arrives at his full growth. It is,

[a] Archives de Zoologie expérimentale et générale, tome troisième, année 1885.

[b] See Prof. D. J. Cunningham's work on Surface Anatomy of Cerebral Hemispheres, p. 286.

however, certain that the largest apes are perfectly developed when man is still in his youth, and that the ape's brain has reached perfection before the period of shedding its teeth, while in man it then takes its real first step to perfection, men of the same bulk as these apes having four times as much superficial brain surface.[a]

Whatever other functions the anterior lobes of the brain perform, the specific structure of their cortical nerve elements, in conjunction with those of the other lobes of the brain, controls our associative memory and our higher intellectual faculties. If we study the collection of preparations of the brains of apes in our museum we must arrive at a similar conclusion to that expressed by Professors Edinger and D. J. Cunningham, which is that the gyri (or convolutions) of the brain of man and of the anthropoid apes are to a large extent similar in anatomical characters, with the marked exception of those convolutions which enter into the formation of the frontal lobes. The superior and the middle gyri of these lobes in anthropoid apes are always much shorter than they are in the brains of average Europeans, and what is of especial importance in the brains of anthropoid apes, the inferior frontal gyri exist only in a rudimentary condition of development. This deficiency is very marked with respect to that area of the left inferior gyrus which contains the nerve elements which control our faculty of articulate language. It seems probable that the rudimentary condition of this gyrus in apes is therefore the anatomical expression of the inferiority of these animals to man in intelligence, our intellectual development depending mainly on our possessing the faculty of speech.[b] It may be, anthropoid apes having only rudimentary, if any, specialized areas of the cortical nerve elements which

[a] The Cranial Affinities of Man and Apes, by Prof. R. Virchow, p. 26. Also Journal of Anat. and Phys., new series, Vol. XIII, p. 275.

[b] The Anatomy of the Central Nervous System of Man, Prof. Ludwig Edinger, M. D., translated from the fifth German edition by Prof. W. S. Hall, 1889, pp. 194, 210. Edinger remarks that "very gradually the mantle of the embryonic brain increases in extent, ascending in the vertebrate series. In the apes belonging to the class of primates it has attained an expansion which borders closely on the relations found in man. Nevertheless, an important factor, besides more unessential relations, still separates it from the stage reached by man. The frontal lobe, still very small in the lower apes, attains a large size in the higher apes, but always remains much inferior to that of man. In man, even, this developmental process is nowise terminated as yet. Differences still plainly occur in the region of the frontal lobe which allow us to infer the possibility of further perfecting. The inferior region of the frontal lobe, which contains the centers of articulate speech, and shows very marked variations in development, is the part more particularly concerned."

Prof. D. J. Cunningham states that "one of the most remarkable characters of the cerebrum of the chimpanzee and orang is the total absence of the frontal and orbital opercula," or the pars triangularis, which contains Broca's nerve center for articulate speech. Contributions to the Surface Anatomy of the Cerebral Hemispheres, by Prof. D. J. Cunningham, Dublin, 1892, pp. 110, 279, 305, where he states that "the inferior frontal convolution of the ape is very different from that of man."

regulate the apparatus necessary for the production of articulate speech, that the other parts of their anterior lobes have remained in a comparatively undeveloped condition; whereas the left inferior frontal lobe of man's brain having become highly specialized, and with it his power of language, the other convolutions of his anterior lobes, which govern his intellectual faculties, have been stimulated to increased action, and in this way the characteristic expansion of the fore brain has been evolved among all the more highly civilized races of the human family.

But our contention is that the factors which govern the growth of the skull differ from those which develop the brain, and that the imperfect evolution of the frontal lobes among anthropoid apes is to a large extent due to the premature ossification of that part of the skull which incloses the fore brain and to the remarkable convexity of the orbital plates of the frontal bone. However this may be, the possession of fully developed anterior lobes of the brain, especially of its left inferior gyrus, is the distinctive character of the central nervous system of all those families of mankind who possess well-developed intellectual capacities. On the other hand, if we compare the skull of an Englishman (with a cranial capacity of 1,575) with that of one of the natives of northern Australia (with a cranial capacity of 1,160), we see what a wide difference there is between the development of their frontal regions and also as to the nature of the sutures of their skulls.[a] (This point is clearly illustrated in the photographs taken from the skulls of "existing races of men," as shown in the lower section

[a] Professor Huxley held that the organization of the human brain had more to do with man's intellectual superiority than either its weight or size, and there can be no question that men having small heads are by no means necessarily wanting in mental capacity; but a well-developed frontal region is a characteristic feature of all the more highly civilized communities of the world, and among such people low intellectual endowments or even idiocy is found to be comparatively frequent in those with abnormally small frontal lobes (see note, p. 103, Man's Place in Nature). We agree fully with Professor Huxley that among all the known races of human beings the brain and its including case, the skull, grow together, and the former does not exercise an absolutely predominating influence over the development of the latter. But it is certain that if the anterior part of the skull becomes a "shut box" early in life, it must control the subsequent size and development of the brain which it contains. Professor Welcker, who studied this subject in a thorough Teutonic spirit, arrived at the conclusion that in European races the frontal suture remains opens up to the adult period of life in one out of nine persons. Among African races it is not found open at the adult period of life in more than one in one hundred and fifty persons; and among the aborigines of Australia no adult skull has yet been observed with an open frontal suture. The well-known French anatomist Gratiolet states as a result of his researches that "not only the growth of the brain ceases sooner in those races in which the sutures close early, but also that there is a difference between the higher and lower races as to the order in which the sutures are closed normally. In the latter the anterior sutures consolidate before the posterior, and in the higher races it is the reverse; the posterior sutures close earlier than the anterior." M. Gratiolet bases an argument for the greater perfectibility of the higher races upon

of the chart which accompanies this oration.) We shall discover from specimens in our museum that the inhabitants of western Europe in the later Tertiary and early Quaternary period, as regards the ossification and form, especially of the frontal region of their skulls, more closely resembled that of the chimpanzee than the race of men now inhabiting Europe.[a]

Since Hunter's and Lawrence's time considerable progress has been made in the sciences of geology and anthropology. Nevertheless, in our search for knowledge concerning the origin and development of prehistoric man in western Europe, we are still hampered by the limited supply of his remains. It could hardly have been otherwise, considering the perishable nature of the human skeleton and the vast length of time and the great geological changes which have occurred since man appeared in our part of the world. But we have additional evidence concerning the prehistoric inhabitants of this part of Europe, for they have left us some of their imperishable handiwork in the shape of flint and stone implements, which, during the past century, have been carefully studied in relation to the geological strata in which they were discovered, by Lord Avebury, Professors Boyd Dawkins and Prestwich, Sir John Evans, the late Sir William Flower,[b] together with many other English and foreign anthropologists. A few characteristic specimens of these Paleolithic flint instruments which have been unearthed in pre-Glacial and in inter-Glacial formations in various parts of England may be seen on the shelves of our museum, which also holds casts and the skulls of the Neanderthal group of men. From the form and workmanship of these stone implements we are now able to classify and assign them to the various periods in which they were manufactured by the early inhabitants of our part of the world.

these facts. On the other hand, Prof. L. Edinger is disposed to agree with the late Professor Perls, that not a few men of preeminent intellectual power have in early life been affected with slight hydrocephalus, which, having abnormally expanded their skulls, has then receded. The brain of such young people has been able to attain a greater capacity than it would have acquired had there been no hydrocephalus to expand the skull cap. (The Anatomy of the Central Nervous System of Man, by L. Edinger, M. D., translated from fifth German edition by Prof. W. S. Hall, p. 206.)

[a] The Origin and Character of the British People, by N. C. Macnamara, p. 25.

[b] Sir William Henry Flower, K. C. B., F. R. S., died on July 1, 1899. He was for some years the conservator of the Museum of the Royal College of Surgeons of England, and the council of the college unanimously passed the following resolution at their meeting on July 13, 1899:

"The council hereby express their deep regret at the death of Sir William Henry Flower, K. C. B., F. R. S., and their sincere sympathy with Lady Flower and the members of his family. The council remember how much Sir William Flower, while conservator, did to advance the utility and reputation of the museum by the skillful discharge of his duties, and by the eminent position which he won for himself among men of science, and they hereby record their grateful appreciation of his services to the college."

Up to within recent times it was held that no human beings existed on the earth before the Quaternary geological epoch. But in the year 1867 the Abbé Burgeois exhibited a collection of chipped flint weapons which he had discovered in a previously undisturbed Tertiary formation; it was not, however, until 1872 that these instruments were admitted to have been made by man or some other animal living previously to the commencement of the Quaternary period. Precisely similar flint weapons have since been discovered in Tertiary strata in various localities in Europe, and in Asia.

In the year 1894 Dr. Eugène Dubois found the upper part of a human skull (calvaria) in close proximity to a femur, and two molar teeth in a well-defined Tertiary geological formation in the island of Java. Dr. Dubois was employed by the Dutch Government to examine and report on the fossil-bearing strata of Java, and while engaged on this work he discovered embedded in a hard mass of Tertiary tuffs the bones above referred to. He brought these fossils to Europe and submitted them for examination to the leading anatomists of this and other countries. They concurred in the opinion that the femur was a human bone belonging to a man of a very low type, and which showed "that while it rendered its possessor capable of the bipedal mode of locomotion, he still retained some vestiges of adaptation to an arboreal existence."[a] There was a difference of opinion concerning the calvaria, for it was calculated the capacity of this skull did not exceed 850 c. c. The cranial capacity of the largest anthropoid ape is 600 c. c. Until the Java skull was found the earliest known human skulls had cranial capacities of about 1,220 c. c. After a complete and exhaustive analysis of the anatomical characters of the Java calvaria, as compared with the skulls of man and apes, Professor Schwalbe has arrived at the conclusion, in which I fully concur, that the Java skull, taking both its form and capacity into consideration, "is on the border line between that of man and anthropoid apes;" it is more closely allied to the skulls of the Neanderthal group of men than it is to the crania of the higher apes, but it is much nearer in anatomical characters to the skull of the chimpanzee than it is to the cranium of the average adult European of the present day.[b] Nevertheless, from a study of the impressions of the convolutions of the brain on the interior of the Java calvaria, Dr. Dubois has demonstrated that the inferior gyri of the frontal lobes are well marked, and approach in form those of man; and although the superficies of this convolution of the brain in the Java skull is less than half the dimensions of that of Europeans of the present day, it is double that possessed by the largest known anthropoid ape. This fact suggests that the Java man had in some slight degree the faculty of speech, and that his intellectual capacity was

[a] Journal of Anat. and Phys., new series, vol. xiii, p. 273.

[b] Zeitschrift für Morphologie und Anthropologie. Professor Dr. G. Schwalbe, Universität Strassburge. Band I, heft 1, 1899, p. 226.

higher than that of any anthropoid ape we are acquainted with.[a] The postorbital index, or narrowing of the Java calvaria, is 19.3 as compared with an average index of existing Europeans of 12. In this respect the Java skull comes nearer to the Neanderthal group than it does to that of anthropoid apes; it also possesses indications of the existence of that characteristically human feature, frontal eminences.

In the employing of skulls which we believe to be the most reliable test of human races, we classify them under three heads, according to the measurements of their cranial indices; in other words, the measurement of the greatest breadth of the cranium expressed in percentage of its greatest length is our guide as to the race to which an individual belongs from a craniological point of view. When the cranial index rises above 80 the head is called brachycephalic, a broad head; when it falls below 75 the term dolichocephalic, or long head, is applied to it. Indices between 75 and 80 are characterized as mesocephalic, intermediate heads. Assuming the length of the cranium to be 100, the width is expressed as a fraction of it, and is known in the living subject as being the cephalic, and in the bare skull as the cranial index. For instance, if the greatest breadth of a skull is 152 mm. and its length is 190 mm., we multiply the breadth (152) by 100, and divide the product by its length (190), which gives us the cephalic index 80.

We have in our museum casts of two crania and other bones, forming part of human skeletons which were found resting on a ridge of calcareous rock overlooking the river Orneau, in the commune of Spy, Belgium. These remains were unearthed with great care, and there is every reason to believe they were originally deposited where they were discovered, being covered over with four well-defined beds of débris and clay, in which were found the bones of the rhinoceros and the mammoth, also flint weapons of the Mousterian epoch.[b] One of these skulls has characters which resemble those of the higher apes, and assimilate still more nearly to the Java skull, indicating the low type of human being of which this cranium formed a part. Its form, like that of the other human inhabitants of Europe as yet discovered in the early geological strata of the preglacial or the interglacial period, is of the long or dolichocephalic type, its sutures are simple, and for the most part are consolidated. We have another cast, presented to our museum by Professor Huxley, one of our most talented and earnest workers in the science of anthropology, taken from the

[a] "The Brain cast of Pithecanthropus erectus," by E. Dubois, Journal of Anat. and Phys., new series, vol. xiii.

[b] The most superficial layer was 9.5 meters thick, and was formed by débris which had fallen from the rock above. The second layer was 3 meters thick, and formed of yellow argillaceous tuffs. The third layer was 6 meters thick, consisting of red clay, in which were numerous Mousterian flints and the tusk of a mammoth. The fourth was yellow calcareous clay, immediately beneath which the human remains with bones of extinct animals were found.

Neanderthal cranium. This cranium, with other portions of a Paleolithic human skeleton, was found in a limestone cave near Düsseldorf.[a] The cave was raised some 60 feet above the existing bed of the river Düssel, and its floor was covered to a depth of 5 feet by fluviatile deposits, beneath which these human remains were discovered. The frontal angle of the Neanderthal and Spy skull (No. 1) is 64°, that of the Java skull is 50°, whereas the existing races of adult male Europeans have a frontal angle of about 90°; in this group of skulls, although still but slight, the indications of frontal eminences are perhaps more distinct than is the case in the Java skull. The skull capacity of the Neanderthal group of human beings amounts to 1,220 c. c., the Java skull to 850 c. c., whereas Europeans of the present day have an average cranial capacity of 1,540 c. c. to 1,600 c. c.

We have in our collection also a skull of the characteristic early Paleolithic type, presented to the college by one of our former presidents whose memory is treasured by all who knew him, Prof. George Busk. It was found in a layer of brecciated talus, under the north front of the Rock of Gibraltar. We have also a cast of the calvaria of one of this race found in county Sligo. Another skull of the same type was discovered at Bury St. Edmunds, with the remains of extinct animals and Mousterian flint weapons.[b]

The anterior surface of the lower jaw among the existing races of Europe projects to form the chin. Among apes the reverse is the case, for the anterior surface of their mandibles recedes. The Malarnaud and the Naulette mandibles, of which we have casts, are evidently those of human beings. They were found in geological formations (which also contained the bones of extinct species of animals and Paleolithic flint weapons). These bones are distinctly ape like in character, having receding anterior surfaces, and also the sockets of all the molars are equal in size. The bones of the legs of these preglacial or interglacial inhabitants of Europe are of ape-like form, and, together with the bones of their arms, prove that they were a short powerful race of beings whose average stature did not exceed 5 feet. They are known as the Neanderthal group of men. The side view of the skulls and that from above of four of the men in this group are illustrated in our chart.

[a] The term "Paleolithic" is applied to geological formations distinguished by containing the rudest shapes of human stone implements associated with the remains of mammals, some of which are entirely extinct, while others have disappeared from the districts where their remains have been found. These deposits may be classed under the heads of alluvium, brick earth, cavern beds, calcareous tufas, and loess. (Class Book of Geology, Sir A. Geikie, p. 361.)

[b] We possess accurate drawings and a description of this cranium. There can be no question that this was a genuine Paleolithic skull, and demonstrated the presence in the county of Suffolk of this race of human beings when England was still connected by land with France.

It should be clearly understood that up to the present time no bona fide human remains belonging to the early Paleolithic period have been discovered in western Europe which were not of the same type as those above described.

When the glaciers which had extended over the greater part of Europe moved northward, the reindeer passed away with them from our part of the continent. These animals, which could be easily captured by man, had roamed in vast herds over the surface of the country, and had probably afforded the human inhabitants of that period, living in western Europe, an ample supply of food. The climate of our part of the world at the termination of the Glacial period became such as we now experience. Britain was separated from France by sea, and fine rivers containing numerous fish filled the valleys of our land; the red deer, wild horse, and various fleet-footed animals abounded in the splendid forests which overspread the country. But these animals and the fish of our lakes and rivers were not easily captured, and the human inhabitants of western Europe were therefore compelled to exert their intellectual capacities to an extent not heretofore necessary in order to supply themselves with food and with the skins of animals for clothing. Man was able to overcome the difficulties he had to face, possessing an innate power by means of which, as already explained, his brain was able to develop and so meet the increased demand made upon it in the struggle for existence. That such was the case we judge from the discovery, in geological formations of the Post-Glacial period, of the skulls of men having the same physical type as those of the strictly early Paleolithic epoch of western Europe, but with increased brain capacity. These Post-Glacial human skulls indicate, in my opinion, a gradual transition in form from the ape-like characters of the previous period to a higher standard, and certainly to a much greater skull capacity, especially in the frontal region. With this improvement in the form of the human skull, the flint, stone, bone, and horn instruments made by the Post-Glacial inhabitants of western Europe become more highly finished than those belonging to the previous age, indicating the possession of increasing intellectual power on the part of those who made them.

The Engis skull, of which we have a cast, presented to this college by Sir Charles Lyell, is a well-known example of a human cranium of the early Neolithic[a] or Post-Glacial period. Huxley, in his description of this skull, observes, "It takes us at least to the further side of

[a] The term Neolithic is used to signify that period in which the stone, bone, and horn implements made by man indicate a considerable advance in the arts of life beyond those discovered in the previous Paleolithic epoch. In the Neolithic period the remains of the mammoth, rhinoceros, and other prevalent extinct forms of the Paleolithic series had almost, if not completely, disappeared from western Europe. The deposits in which these Neolithic remains are found consist of river gravels, cave floors, peat bogs, raised beaches, etc.

the biological limit which separates the present geological epoch from that which preceded it;" that is, from the Glacial period." The Borris skull probably also belongs to this period, its characters being similar to the Tilbury cranium described by Sir Richard Owen, and of which we have a cast in our museum. To this list of Post-Glacial—or it may be of the later Glacial -period we may add the Egisheim calvaria, or so much of it as has been preserved. This specimen, of which we have a cast, was discovered in a high river bed near Colmar with the bones of extinct animals and Mousterian flint weapons. These and various other skulls found in geological formations of the time referred to are all of the same type, and lead us to believe that the inhabitants of Europe in the early Neolithic period consisted of only one race—the descendants of the human beings who inhabited our part of the world during the previous or Paleolithic epoch. They had long (dolichocephalic) skulls, with slightly projecting supraorbital ridges, well-formed noses, and a fairly developed frontal region as compared with the far more ancient Java, Spy, and Neanderthal crania. Their mandibles and the bones of their legs were less simian in character than those of their remote progenitors. They were a small race of beings. We find no metal weapons or instruments with their remains, and we therefore conclude that they were ignorant of the use either of bronze or of iron, nor do they seem to have possessed domestic animals or to have had any knowledge of agriculture.

This race of primitive inhabitants of western Europe are best described as the Iberians, and we may conveniently employ this term so long as it is understood to designate the Africo-European stock, who were, so far as we know, the sole human inhabitants of western Europe after the termination of the Glacial epoch.

As we pass from the early to the mid-Neolithic epoch, we come upon the remains of a race of men who, as regards their physical character and state of civilization, essentially differ from the people above referred to. The stone implements found with their skeletons are beautifully formed, many of them being highly polished and having sharp cutting edges. A few of the purest bronze ax heads have been discovered with these remains, and also the bones of domestic animals belonging to species indigenous to Asia, but foreign to the Paleolithic fauna of Europe. Lastly, we have evidence that these people were acquainted with agriculture and with the manufacture of sun-dried pottery. They paid great respect to their dead chiefs, burying their bodies in natural caves, or in tombs formed of huge flagstones placed edgewise side by side, with similar stones laid on the upright ones to form the roof of the building. These structures, the well-known long dolmens, have been found, built on precisely the

"Man's Place in Nature, by Professor Huxley, p. 120. For a description of the Borris skull, see S. Laing and Professor Huxley's Prehistoric Remains of Caithness.

same plan, in Ireland, England, the greater part of Europe, the west of Asia, India, Arabia, and northern Africa. The construction of these dolmens, wherever met with, is so similar in style that we conclude they were the work of one race, or at least of one special confederacy of races. They were not only sepulchers for the dead, but many of them also contained an altar, a place of mourning and of offering, where intercession was made to the spirits of departed chiefs by their relations and tribesmen. The Rodmarton long dolmen or temple tomb (near Cirencester) affords us a good example of one of these structures; it is 180 feet in length and 70 feet broad. We have in our museum a fine human skull which was found in this dolmen, with some well-polished stone implements. If we compare this skull with that of the Java or the Neanderthal group of men or with the skulls of the early Neolithic human inhabitants of western Europe, we are struck by the marked difference that exists between them and the Rodmarton skull. Dr. Thurnam's unique collection of crania may be seen in the Anatomical Museum, Cambridge. These crania for the most part were unearthed by himself from various English long dolmens and barrows, and they resemble in form, although they are of a higher type than, the skulls found in the caves of Cro-Magnon and Mentone; they are identical in character with skulls found in the long dolmens of France and other countries of Europe. The cranial index, capacity, and other features of the bones of these skulls lead us to assign them all to one and the same race, of which the Cro-Magnon are probably some of the earliest specimens as yet discovered in western Europe. The three Cro-Magnon and three Mentone skeletons were those of people some 6 feet 4 inches and upward in stature, so that a race of giants in far distant times was no myth. Their cranial capacity was above that of the average Europeans of the present day. From their physical conformation and from the remains of the animals found buried with them, which are of Asiatic species, and from other evidence, we are led to the conclusion that the Cro-Magnon race represent the advance guard of the proto-Aryan human family, of which the Rodmarton[a] and many other long dolmen skulls show a more advanced type. These people in far distant ages migrated from the East into western Europe, and from thence spread into our islands; southward they passed into India, Persia and Arabia, Asia Minor, and northern Africa. Over this vast area and far away in eastern Asia we find their remains, with flint and stone implements of the early Neolithic type, buried in long dolmens or barrows. The roots of many of the words used by this ancient people exist in most

[a] In the History of Ancient Wiltshire, by Sir H. C. Hoare, Vol. I, pl. xvii, p. 164, there is an account of a skull found in a long barrow near Stonehenge, which is now to be seen in the Anatomical Museum at Cambridge (No. 180A), of which I have a photograph.

of the languages now spoken in Europe; their religious sentiments, myths, and, above all, their racial, mental, and physical characters, as portrayed in the Rig-Veda and on the ancient monuments of Egypt, are pronounced features in the existing Teutonic and Anglo-Saxon people. From the form of the crania found in many of these long dolmens we know that this tall, fair, handsome, long-skulled race intermarried with the preexisting short, dark Iberian inhabitants of Europe. The fair, tall race probably did not at any time, unless in the north of Europe, form a large proportion of the population. They were a dominating, fighting, and priestly caste, who compelled the primitive, small, dark (Iberian) inhabitants of western Europe to work as their slaves.

During the Neolithic era, while the descendants of the proto-Aryan stock were slowly feeling their way from the East along the valley of the Danube into Europe, a very different race were passing from northern Asia into the Baltic provinces. These people formed settlements on the islands of Denmark and westward as far as the north of Ireland. They were the first of the broad-skulled races of the human family who had entered Europe. Their skulls were brachycephalic in form, with broad faces and noses, the latter being deeply concave at the base. Their remains are found in the islands of Denmark, especially that of Möen, also in Yorkshire, Derbyshire, Staffordshire,[a] and in Cos. Antrim and Tyrone,[b] in which localities their descendants may still be recognized by their physical characters. They buried their dead and did not practice cremation, as did the Mongolians of the bronze age in Europe. These people belonged to the stone age of Europe, and by comparing their skulls with those of the Rodmarton or Cro-Magnon crania we see the great difference in form of the prehistoric long and the broad-headed races of men.

Until the close, therefore, of the Neolithic epoch there were three pure races who formed the sole human inhabitants of Europe, so far as we can judge from their skulls and other remains, with the exception of those who were the outcome of the intermarriage of these three races of people with one another.

Passing from the Neolithic to the succeeding bronze age, we believe that Europe was overrun by a small, broad-skulled people having characteristic Mongoloid features. These people were probably, in their Asiatic home, originally derived from the same stock as the tall, fair, broad-skulled North Mongolian race above referred to. But the southern Mongoloid people of the bronze age in Europe were a small race of men with dark hair and eyes. These were the early lake dwellers of Switzerland and other parts of Europe. Prof. A. C.

[a] Crania Britannica, tables on, pp. 241–244.

[b] Prof. A. C. Haddon. See Studies in Irish Craniology, Proceedings of Royal Irish Academy, vol. iv, p. 577.

Haddon is disposed to think that before their arrival in our islands these people had become a mixed stock through intermarriage with the Iberian or Mediterranean race. (In the dolmen at Meudon we find the remains of a man of the broad and a woman of the long skulled race placed side by side.) They were traders in bronze, and probably, as Prof. G. Mortillet and other authorities hold, gradually replaced stone, horn, and bone with bronze instruments and weapons, effecting in this way a great revolution in the social and industrial habits of the preexisting inhabitants of western Europe. In these far distant times deep mining operations were out of the question. Superficial ores of copper were abundant in most parts of Europe and in Asia, but alluvial tin was extremely scarce, and it is still only found in large quantities in southeastern Asia. Cornwall, the Scilly Isles, the south of Ireland, and some few other places on our continent also contained superficial ores of tin. It seems probable that the Mongolians inhabiting the highlands of southeastern Tibet, long before the commencement of the bronze age in Europe, spread into Burma, the Malay Peninsula, and Cochin China, and there acquired the art of mixing copper and tin in such proportions as to form bronze, the weapons and instruments which they manufactured of this metal being a ready and profitable source of barter in Europe. These people, without doubt, made bronze weapons both in the south of England and of Ireland, for clay molds have been found there in which weapons of the early bronze period in Europe were cast.

Together with the broad skulls and other remains of these people we find in the débris of the lake dwellings numerous ornaments of jade, nephrite, and chloromelanite, minerals found in large quantities in southeastern Asia, but not in Europe; and lastly, vases on which are depicted people in Oriental costume, and instruments used only by the southeastern Tibetans have been discovered in connection with the remains of the lake dwellers. It is almost unnecessary to remark that, although many millions of Hindus have in successive periods occupied the greater part of Bengal, it would be impossible to discover their bones in the soil, for the simple reason that they have either burnt the bodies of their dead or else cast them into one of the sacred rivers of India. And so it is with the skeletons of these southern Mongoloid people of the bronze age in Europe. As a rule their bodies were cremated after death, and numerous cinerary urns containing their remains are found scattered over the Wiltshire and other ranges of hills in the south of England. Some few of their skeletons, however, have been found in the round barrows which are so numerous, especially in the south of England, of Ireland, and throughout various other parts of Europe, and in Asia. With these remains and cinerary urns very many bronze instruments have been met with, indicating, like the stone implements of the Palaeolithic period, different stages of

excellence in workmanship.[a] The size of the handles of the bronze knives and other weapons, as well as the bangles, prove that the people who used them were a small race of men and women, we believe best represented in Europe by the prehistoric short inhabitants of Auvergne.[b]

One of the finest skulls in our museum was taken from a round barrow at Codford, Wilts, and although this skull must be at least five thousand years old it still seems as if it were full of life and fun (see illustration), characteristic features of the race to which it belonged. The form of this brachycephalic skull, together with its nasal bones and orbits, are clearly Mongoloid in character, and are well known to those of us who have lived in India as representing the Ghurkhas and Burmese of the present day. A lazy, bright, rollicking people, intensely superstitious and home loving—"the Irish of the East," as they have been aptly called. In the course of many centuries the southern Mongolian people of western Europe have unquestionably become absorbed into the preexisting Ibero-Aryan population; a cross breed has resulted, and from this stock the ancient British people of our islands were derived. Their skulls are mesocephalic (a combination of the long and broad skull), and are amply represented in our museum, the cephalic indices being about seventy-eight.[c] Subsequent to the bronze age the ancient Britons were well-nigh exterminated in England by Teutonic races, who invaded our country from the north of Europe, the Anglo-Saxons taking the place of the preexisting ancient British population of England and Scotland. Nevertheless, in some districts of England, such as North Bedfordshire, a number of the descendants of the ancient British stock continue to flourish up to the present day, as also in the greater part of South Wales, much of Cornwall, and the south and west of Ireland, the upper classes in Ireland being clearly derived from the ancient Aryan stock who passed from Gallia into that country during the Neolithic period. The illustrations show a characteristic head and face of one of the descendants of the ancient British race and also of a typical Anglo-Saxon.

Passing from prehistoric to the present time, we have come to possess the measurements of the heads of some 25,000,000 of the existing inhabitants of Europe.[d] From these measurements we learn that a large proportion of the people now dwelling in the countries bordering on the Mediterranean Sea are a short, brunette, long-skulled race,

[a] The Ancient Bronze Implements of Great Britain, by Sir John Evans.

[b] Formation de la Nation Française, par G. De Mortillet, Professor à l'Ecole d'Anthropologie, pp. 257, 269–270. See also The Dolmens of Ireland, by A. C. Borlase, pp. 1012–1014.

[c] The Mongolian cephalic index being from eighty upward, and that of the Ibero-Aryan seventy-five and below that figure.

[d] The races of Europe, by W. Z. Ripley, p. 34.

descended, we believe, from those who, from the form of their skulls and other physical characters, occupied that part of Europe and the north of Africa in far distant ages—the Iberian race.

Scandinavia and North Germany are inhabited by a tall, fair, long-skulled people derived from the proto-Aryan races who settled in that part of our continent in the Neolithic epoch. A vast triangle having its base in eastern Russia and its apex on the Atlantic in southwestern France is inhabited by the broad-skulled people derived from Mongoloid or Turanian ancestors. We do not for a moment affirm that these races, as such, have remained pure—far from it; but the results of the measurements of the heads of a great number of the existing inhabitants of Europe point to the conclusions above indicated; and this idea is confirmed by the cranial indices of the splendid collection of crania which occupy so large a space in the museum of this college—a collection which was commenced by John Hunter, and upon which during the past century a great amount of time and labor has been spent in describing and classifying the skulls which it contains.[a] Our collection has been added to and kept well up to date by Prof. C. Stewart, and might, I think, with advantage to science, be utilized in an effort to solve the debatable question of the connection between the Neanderthal group of men and the postglacial inhabitants of western Europe.

The characteristic physical type of paleolithic man may be still recognized among the inhabitants of western Europe, although their skulls have grown more capacious, especially in the frontal region. This change in the form of the cranium marks a corresponding advance in the capacity and organization of the brain and of the intellectual ability of man; it is in truth evidence of his inherent power to overcome the demand made on his mental capacity in order to cope successfully with his ever-increasing struggle for existence, consequent on the growth in number of his fellow-creatures and the more complicated social conditions of his surroundings. Doubtless the form of skull of a large proportion of the inhabitants of our island indicates a cross breed formed by the intermarriage of the long and broad skulled families of man who in distant ages met and intermarried in western Europe, thereby improving the stock of their descendants. Races of men, such as the natives of Australia, who have remained in an unchanged environment and without intermarriage with other people, have made but little progress in their intellectual capacity, the form of their skulls continuing of the same type as those possessed by the paleolithic inhabitants of Europe.

[a] We have about 4,000 skulls in our museum, arranged according to the countries of which they are presumably native. All these specimens have been accurately measured and described in our catalogue, either by Sir W. Flower or by Mr. L. McAra, under Prof. C. Stewart's supervision.

The same causes to which we have referred, acting for long periods of time on people of the same race, have not only led to the hereditary transmission of their physical characters, such as those existing respectively among the northern, central, and southern inhabitants of Europe, but have also developed specialized areas of nerve structure in their brains, by means of which they have come to think, feel, and reason alike; thus having an inherent, widely-diffused individuality. In this way we are able to comprehend the source and the meaning of large bodies of men belonging to the same race being frequently moved to take common action on matters affecting the well-being of their race; they possess, in fact, like innate sentiments, or racial characteristics, although separated from one another by great distances and living under diverse climates and environment. Their emotions and ideals harmonize, because their progenitors existed for many ages under similar external conditions, and consequently developed like specialized nerve centers, which have been transmitted, together with their physical characters, to their successors, and become crystallized in their laws, and reflected in their conceptions of religion as well as in their social institutions.[a]

In illustration of our meaning we may refer to those revolting pages of history during which Belgium and the Netherlands passed under the dominion of Spain, the Iberian dominating for the time being over a thoroughly Teutonic race. Or we may contrast the existing condition of the Iberian population of South America with the Teutonic Anglo-Saxon inhabitants of the United States, or that of the latter with the negro population of America.

We have a chart here which shows the result of the recent general election held in this country; the question at issue was one in which the whole of the people of Great Britain were deeply interested. It is remarkable what a large proportion of the inhabitants of England and of Scotland, mainly of Anglo-Saxon origin, voted together on this subject; whereas a contrary opinion regarding this same question was held by the greater proportion of the people of Ireland, and to a large extent by the Welsh, most of whom are derived from Ibero-Mongolian ancestors. It is difficult to account for the diversity in the sentiments of the people above referred to, unless we consider it due to their racial mental qualities.[b] Environment has doubtless played an impor-

[a] The Origin and Character of the British People, by N. C. Macnamara, p. 192. See also the Westminster Review, December, 1900, p. 634.

[b] This idea is confirmed by the result of the elections that have lately taken place in Canada and in the United States of America. The younger branches of our Anglo-Saxon race, forming by far the larger proportion of the inhabitants of these vast and flourishing dominions, had to solve a similar question to that placed before the people of Great Britain, and they have responded by a vast majority to this call, on precisely the same lines as those followed by Englishmen, moved, we believe, by common racial inherent sentiments.

tant part in the evolution of these people, but their inherited racial character has had more to do with the position which the Anglo-Saxon race has gained in the world than the mineral wealth, climate, or protection afforded us by our seagirt coast.

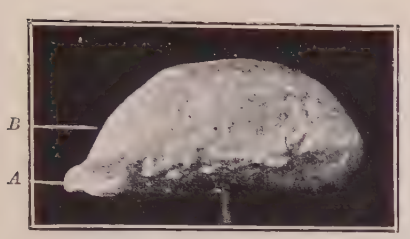
The environment under which even a few generations of men exist would seem capable of influencing the structure of their central nervous system, as illustrated by comparing the mental qualities of our rural and urban population. The conditions under which the city-bred child and man live engender in the course of a few generations an unstable state of nerve structure, resulting in an excitable character, which, if carried beyond a certain point, leads to unsoundness of mind, and may account for the increasing number of lunatics in this and the other large cities of Europe. Gen. Sir Redvers Buller again, in speaking of the soldiers under his command in South Africa, refers to the fact that our city-born men have imperfect sight compared with men reared in the open plains of the Transvaal, thus affording us another example of the effects of environment on the race.[a] These are a few of the many interesting and important subjects which arise in connection with the study of anthropology, including craniology; and the contents of our museum and library offer unrivaled opportunities to the student seeking for knowledge in these branches of science.

In conclusion, as already stated, much of Hunter's reputation was founded on the result of his labors in those branches of science which tend to elucidate man's nature; and during the past century a succession of English surgeons have carried on the work commenced by our great master, enriching our museum and endeavoring to make this college not only an examining and licensing body, but what it certainly should be—an imperial institution for the cultivation and diffusion of those departments of knowledge which bear on comparative anatomy, physiology, or surgery. The ideas entertained by John Hunter's immediate successors on this subject were ably stated by Sir William Lawrence, in his lectures already referred to, when he observes that "our own individual credit and the dignity, honor, and reputation of our body, which we are bound to maintain, demand that surgeons should not be behind any other class of the community in the possession either of the cultivation of those branches of knowledge which are directly connected with surgery or in any of the col-

[a] Sir Redvers Buller in one of his speeches is reported to have stated that "in the first instance, many of our men are city born, and England is not a very large country. We went out to a region where the principal number of our enemies were born in a very open country, a very large country, and it is not untrue to say that practically the vision, the ordinary sight, of our enemy was 2 miles, at least, farther than the average sight of the English who were fighting against them. That is a matter of actual fact. An ordinary Dutchman or African can see a man coming toward him 2 miles before the man approaching can detect him."

lateral pursuits less immediately attached to it." Sir William continues: "It is only in reference to such views and objects that the Hunterian collection could have been accepted or can be of any use to this college."[a] Hunter would, had he still been with us, have thrown all his indomitable energies into the successful working of such an institution, and amidst the turmoil, strife, and competition going on around him, would, as we see him in this picture, have been engaged in the earnest, accurate, patient study of nature. It remains for our younger members to emulate the example set them by John Hunter, and by such service secure for themselves lasting satisfaction and add to the real dignity and utility of this college and of their profession.

[a] Lectures on Physiology, Zoology, and the Natural History of Man, delivered at the Royal College of Surgeons by W. Lawrence, F. R. S., 1819, p. 497.

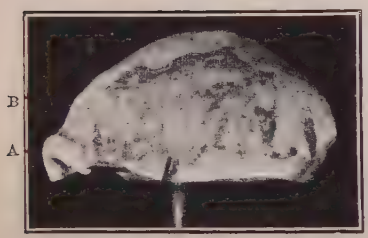


SIDE VIEW OF THE JAVA SKULLCAP.

Showing the ape-like projection of bone above the orbits, the low receding forehead, and absence of cranial sutures. *B*, Receding forehead; *A*, projection of bone above orbits.



JAVA SKULL, AS SEEN FROM ABOVE (NORMA VERTICALIS).



SIDE VIEW OF THE SPY (NO. 1) SKULLCAP.

With prominent ridges (*A*) above orbits and receding forehead (*B*).



SPY (NO. 1) SKULL (NORMA VERTICALIS).



SIDE VIEW OF NEANDERTHAL SKULLCAP.

Showing prominent ridges above the orbits, receding forehead, and absence of cranial sutures.



NEANDERTHAL SKULL (NORMA VERTICALIS).



SLIGO SKULL (NORMA VERTICALIS).



SIDE VIEW OF SLIGO SKULLCAP.

Ape-like prominence (*A*) above orbits; receding forehead (*B*), and absence of sutures.



SIDE VIEW OF GIBRALTAR SKULL.



FRONT VIEW OF GIBRALTAR SKULL.



EGISHEIM CALVARIA (NORMA VERTICALIS).



SIDE VIEW OF THE EGISHEIM CALVARIA.

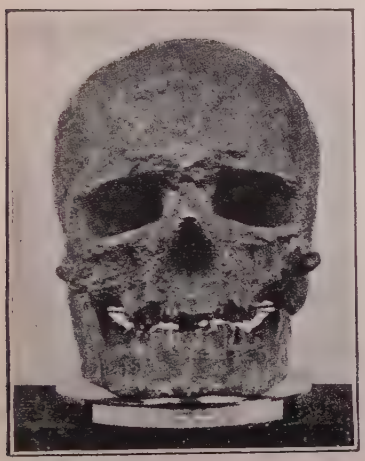


SIDE VIEW OF THE TILBURY SKULLCAP.

Prominence over eyebrows still marked (*A*), but the forehead more developed (*B*), and indications of sutures to be seen.

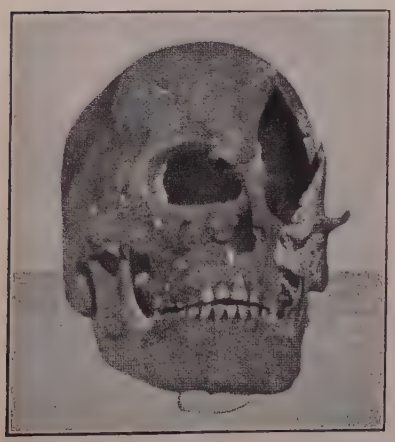


TILBURY SKULL (NORMA VERTICALIS).



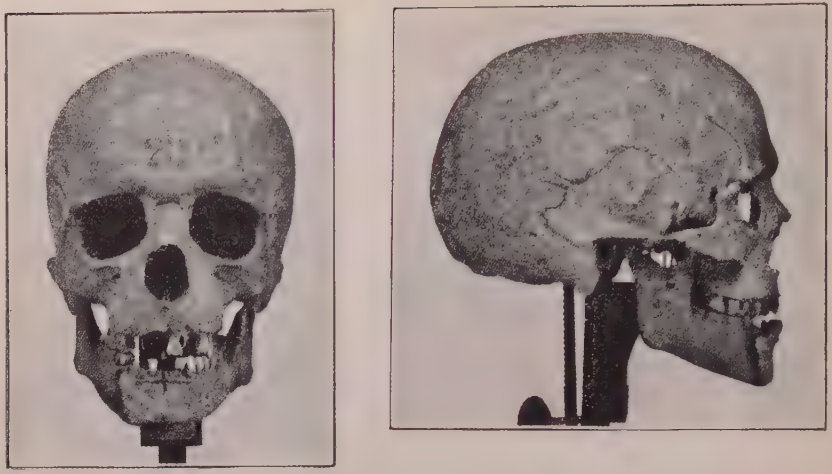


FRONT AND SIDE VIEWS OF A CRO-MAGNON SKULL.

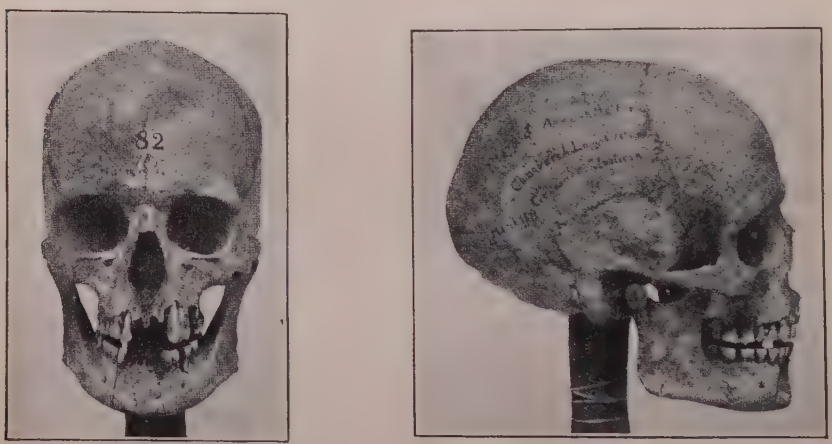




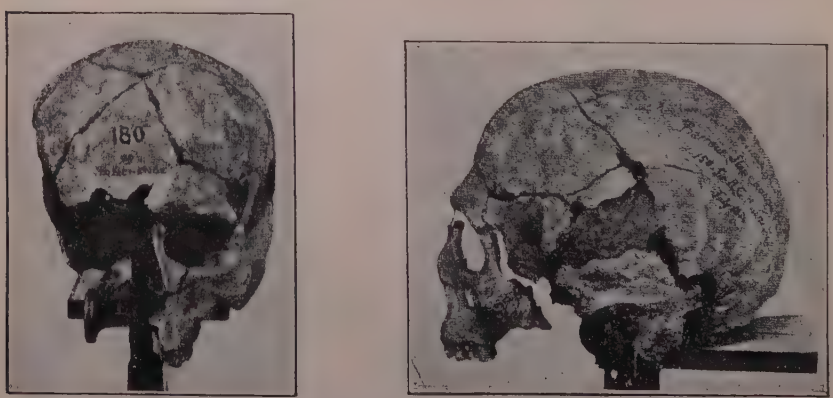
FRONT AND SIDE VIEWS OF MENTONE SKULL.



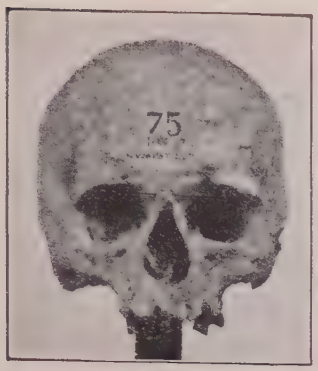
FRONT AND SIDE VIEWS OF ONE OF THE SKULLS FOUND IN THE RODMARTON DOLMEN, EARLY NEOLITHIC PERIOD.



FRONT AND SIDE VIEWS OF LONG BARROW SKULL FROM GATCOMBE, GLOUCESTERSHIRE.



FRONT AND SIDE VIEWS OF SKULL FROM A LONG BARROW NEAR STONEHENGE.

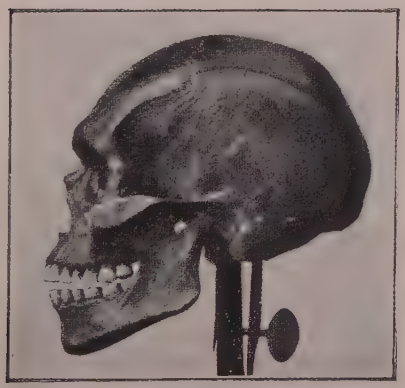




FRONT AND SIDE VIEWS OF NYMPSFIELD SKULL.



A BRACHYCEPHALIC SKULL FOUND IN A BARROW AT CODFORD, WILTS.



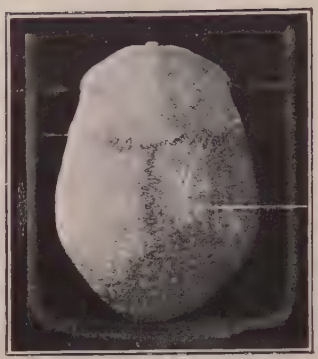
SIDE VIEW OF SKULL OF NATIVE OF AUSTRALIA.



SKULL OF NATIVE OF AUSTRALIA OF THE PRESENT TIME (NORMA VERTICALIS).



SIDE VIEW OF SKULL OF ENGLISHMAN.



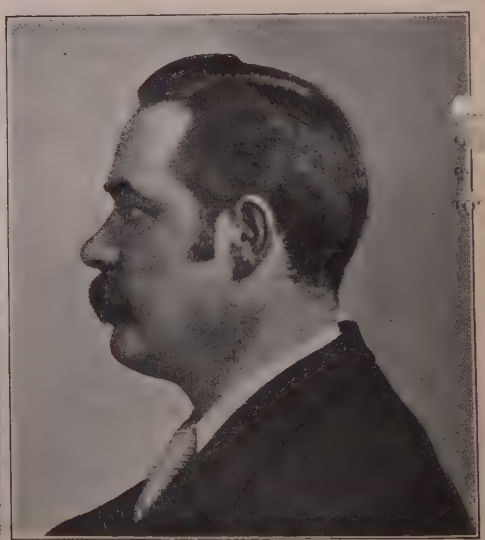
SKULL OF AN ENGLISHMAN OF THE PRESENT TIME (NORMA VERTICALIS).

A, Coronal suture of skull; *B*, sagittal suture.



IBERIAN TYPE FROM NORTH BEDFORDSHIRE.

Black hair, dark-brown eyes; stature, 5 feet 5 inches. Cephalic Index, 72.3.



ANGLO-SAXON TYPE FROM KENT.

Blue-gray eyes, light-brown hair; stature, 5 feet 11 inches. Cephalic Index, 78.8.

THE BAOUSSÉ-ROUSSÉ EXPLORATIONS: STUDY OF A NEW HUMAN TYPE, BY M. VERNEAU.[a]

By Albert Gaudry,
Member of the Institute of France.

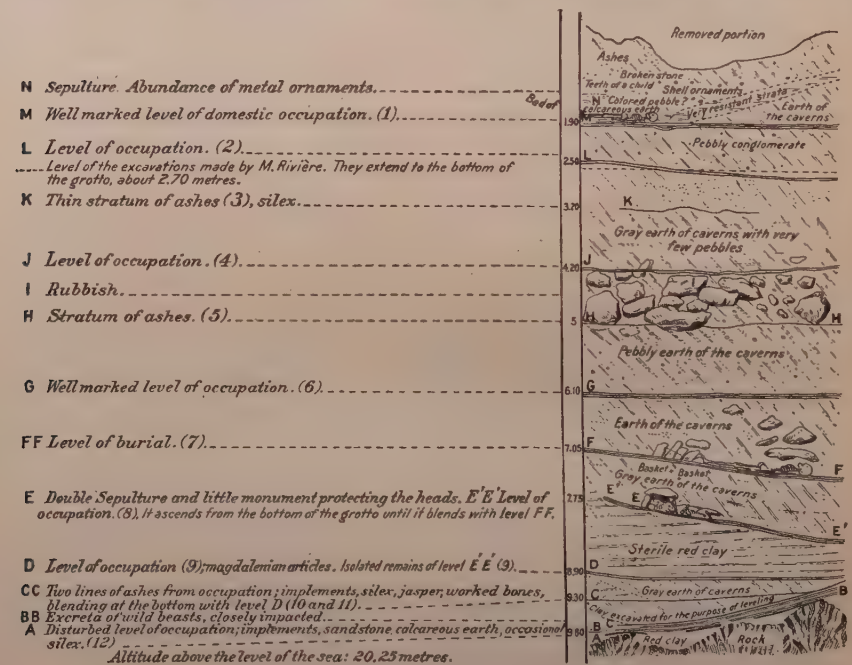
The Prince of Monaco delights not only in exploring the depths of the oceans of to-day, he also loves to explore the depths of the past. He has undertaken to excavate the Baoussé-Roussé on so vast a scale that the place is destined to throw much light on the history of primitive man.

The name Baoussé-Roussé (Red Rock) is well known to scientists since the discoveries of M. Émile Rivière. A large quantity of material has been taken from its various grottoes; in one of them was found the celebrated skeleton of the Jardin des Plantes, known as the Man of Mentone. The Prince of Monaco enlisted as his assistants several French scientists: The Abbé de Villeneuve methodically directs the excavations, removing each stratum separately so as to clearly establish the succession of the phases of prehistoric times; M. Marcelin Boule, so well versed in quaternary paleontology, assumes the examination of the various fossil animals; M. Émile Cartailhac, the eminent corresponding member of the Institute, works at unearthing the human skeletons which M. Verneau, the assistant of M. Hamy at the Museum, is studying with his usual skill. It would be impossible to bring together scientists more capable of successfully carrying out the great enterprise of the Prince of Monaco.

One of the grottoes in particular has furnished to the Abbé de Villeneuve results of considerable importance. This is the Grotto des Enfants, so called because, in 1874, M. Émile Rivière discovered there two skeletons of children which to-day are in the collection of the Catholic Institute directed by M. de Lapparent. In the accompanying figure (see p. 452) there is shown a section of the various deposits and levels of domestic occupation down to the rocky floor of the grotto. In the first seven meters the Abbé de Villeneuve found abundant remains of animals, human utensils, and even two human skeletons. These specimens added nothing particularly new to what

[a] Translated by permission of the author from La Nature, Paris, No. 1511, May 10, 1902.

had already been found in the Baoussé-Roussé by MM. Émile Rivière, Verneau, and others. At the depth of 7 meters and below, however, M. de Villeneuve made some curious discoveries whose true value has been brought out by the discerning mind of Dr. Verneau. At that level there is a stratum in which are found the remains of the cave hyena and Mousterian implements.[a] Nothing is disturbed, and we are therefore certain that we are well within the paleolithic age. Here the Abbé de Villeneuve has wholly uncovered what he calls a double sepulture. As shown in the accompanying plate, there are two skeletons—one that of an old woman, the other that of a young man—placed side by side, in a perfect state of preservation, the limbs



Section of Grotto des Enfants (by the Abbé de Villeneuve).

bent up toward the chin, stones being placed so as to protect the heads. Formerly there was much discussion as to whether paleolithic men honored and buried their dead. MM. Cartailhac and Émile Rivière maintained that they did so. The explorations instituted by the Prince of Monaco confirm their assertion and put the matter beyond doubt.

From a study of these heads Dr. Verneau obtained the following results:

In the upper half they show quite superior characters; they are well developed, with fine foreheads. On examining the lower half, however, a prognathism is found, more marked than has hitherto

[a] See table of classification in Report of Smithsonian Institution for 1901, pp. 439, 440.

PLATE I.



HEAD OF YOUNG MAN.

HEAD OF OLD WOMAN.



THE DOUBLE SEPULTURE.

been noted in any neolithic or paleolithic fossil men, greater even than in the skulls of Spy, in Belgium, which have been so well studied by MM. Fraipont and Lohest, and which bear in certain respects marks of inferiority. The shape of the chin corresponds to this prognathism, it being straight instead of projecting forward as in the superior races. Besides, M. Verneau found on each side of the base of the nasal opening a groove characteristic of the negro. So it seems that, in a deposit belonging to the paleolithic age, beside the remains of the cave hyena whose descendants inhabit southern Africa, there are found human remains with crania having in the lower part negro characteristics, in the upper those of the white race. Is it possible that Dr. Verneau has found a connecting link between the African and the Caucasian types, and that we have here the skeletons of two beings who represented this transition? Such a conclusion would be premature, but we may at least say that he has found a negroid element hitherto unknown among the paleolithic or neolithic men of Europe. Anthropologists and paleontologists owe their thanks to the enlightened prince who is aiding them to discover the mysterious history of prehistoric man.

FOSSIL HUMAN REMAINS FOUND NEAR LANSING, KANSAS.[a]

By W. H. Holmes.

The fossil remains of two human beings were discovered while digging a cellar tunnel for the storage of fruit on the farm of Mr. Martin Concannon, near Lansing, Kansas, in February, 1902. During the past summer the site was visited by a number of geologists, archeologists, and others interested in the history and antiquity of man in America, and already several more or less elaborate accounts of the discovery have been published in our scientific journals. The last and by far the most critical study is that of Prof. T. C. Chamberlin, which appeared in the Journal of Geology for October and November, 1902. Other papers are by Prof. S. W. Williston (Science, August 1), Mr. Warren Upham (Science, August 29; also American Geologist, September), and Prof. N. H. Winchell (American Geologist, September).

I had the good fortune to accompany Professor Chamberlin on his first visit to the site, and to meet there also Prof. R. D. Salisbury, Prof. Samuel Calvin, Dr. Erasmus Haworth, Dr. George A. Dorsey, and Mr. M. C. Long. Careful examinations were made of the tunnel and of the geological formations in the vicinity, as well as of the cranium preserved in the Kansas City Museum, and it was found that the accounts of the discovery previously published were essentially correct in every important particular. The human remains consist of a skull and a number of the larger bones of an adult man and the lower jaw of a child of some ten years.

Owing to the difficulty of studying the formations in the tunnel, already well filled with farm products at the time of our visit, the idea of making additional excavations was suggested, and through the kind offices of Mr. Long it was arranged with Mr. Concannon that the Bureau of American Ethnology should undertake this work. Mr. Gerard Fowke, who, under my supervision, had been conducting researches in the well-known fossil bone beds of Kimmswick, Missouri, was called in, and during the month of October a trench was opened into the relic-bearing deposits from the west at right angles to the

[a] Reprinted by permission from the American Anthropologist (N. S.), vol. 4, October–December, 1902.

tunnel dug by the Concannons, exposing the full depth of the deposits for a horizontal distance of about 40 feet. Besides this the main cellar tunnel was carried some 12 feet farther, and a chamber was excavated on the east side of the tunnel, opposite the point where the remains of the man were found. When this work was completed Professor Chamberlin joined me in a second visit to the site, and examinations of all the phenomena were made under the most favorable conditions.

In the following brief summary I rely for geological interpretations largely on the views of Professor Chamberlin, whose mastery of the intricate problems of glacial and post-glacial geology is everywhere acknowledged.

The remains were found beneath 20 feet of undisturbed deposits forming a little bench on which the Concannon dwelling stands. The child's jaw was encountered about 60 feet from the entrance of the tunnel and the skull of the man 10 feet farther in. There can be no doubt of the correctness of these observations.

The skull is well preserved and corresponds closely in type with crania of the historic Indians of the general region. It presents no unique features and offers no suggestion of great age or of inferior organization. Front and back views are presented in Pl. I and profile and top views in Pl. II. Its characteristics are briefly summarized by Dr. Dorsey as follows:

"The specimen, after such reparation as has been possible, lacks all the bones of the face and small portions of the occipital, temporal, and frontal bones; hence no observations are possible on the face or base of the skull.

"The bones are firm, hard, and comparatively thin. The sutures are moderately serrated.

"From above the skull is ovoidal in form, with somewhat bulging parietals and occiput. The glabella is only fairly high; the supra-orbital ridges near the glabella are well marked. The forehead retreats gradually and is uniformly convex. The vault reaches a considerable height and retreats rapidly to near inion. The occipital region bulges decidedly.

"The temporal lines are fairly well marked, but not pronounced, and extend slightly above the middle of the parietals. The mastoids, though much damaged, were evidently not above medium. The occipital ridges, with the exception of the superior one, and the ordinary occipital depressions are very faint.

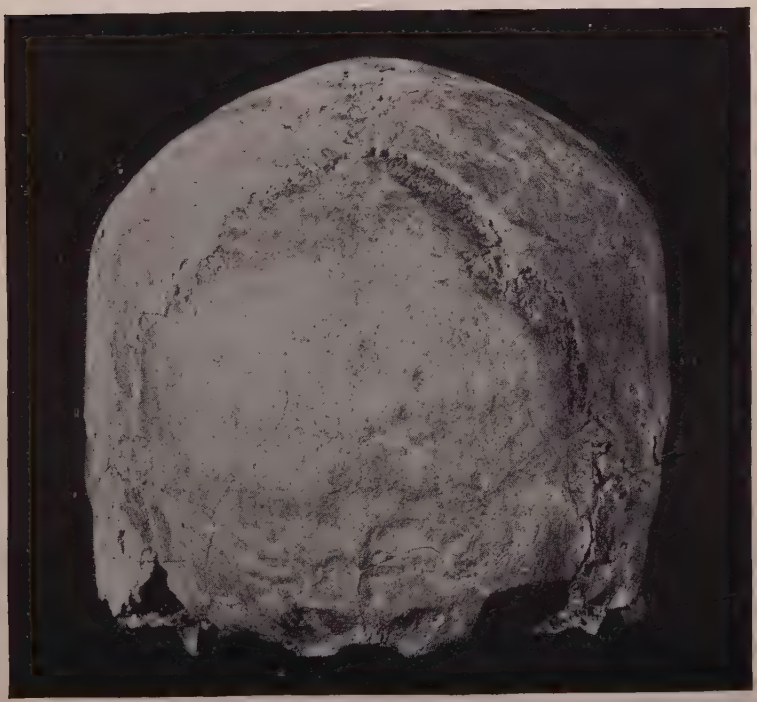
"The skull is of an individual probably from 40 to 50 years of age, and, I am inclined to believe, that of a male. In its general shape the skull bears a striking resemblance to the crania of the Plains Indians, for example, the Blackfoot. Its measurements are as follows:

"Maximum length	189 mm.
"Maximum breadth	139 mm.
"Cephalic index	73.5"

The only question likely to give rise to serious discussion is that of the age of the formations with which the remains were associated, and



a

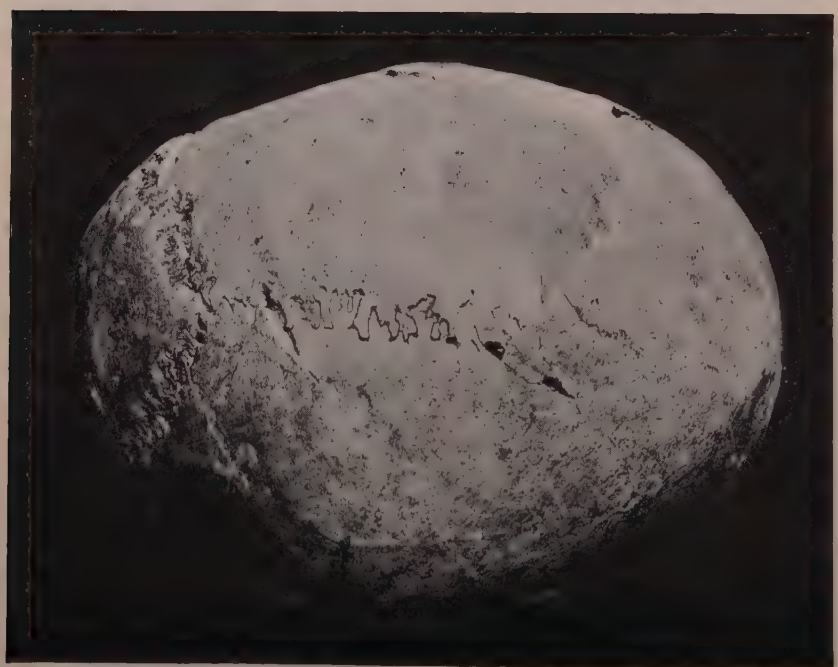


b

THE LANSING SKULL. (FRONT AND BACK VIEWS.)



c



d

THE LANSING SKULL. (SIDE AND TOP VIEWS.)

to this point I shall give chief attention. The bench occupied by the Concannon dwelling is squarish in outline, having a horizontal extent of about 150 feet from east to west and perhaps 160 feet from north to south, and its highest point is about 30 feet above the present flood plain of the river (see fig. 2). It rests against the base of a limestone spur of the river bluff, on the south side of a little valley that opens out into the river bottom at this point. The upper surface of the bench slopes away at a low angle from its junction with the limestone spur (*a*). Facing the river it presents a steep slope continuous with the face of the river bluff. On the north it descends abruptly to the bed of the rivulet, and on the west the slope is somewhat gentle to the small lateral valley on that side.

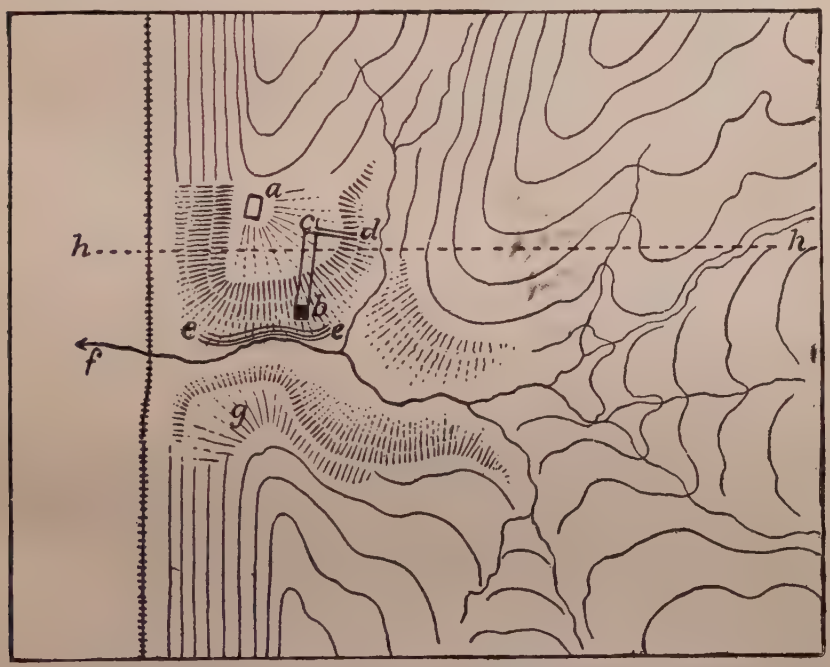


FIG. 1.—Sketch map of the Lansing site, indicating recent bench remnants in hachures. (*a*, Concannon dwelling and point of contact of limestone river bluff with recent bench. *b*, Entrance to cellar tunnel. *c*, Inner end of tunnel where skull was found. *d*, Trench opened by Bureau of American Ethnology. *e–e*, Outcrop of limestone in rivulet bed. *f*, Entrance of rivulet to Missouri River flood plain. *g*, Contact of limestone spur and bench remnant on north side. *h–h*, Line of section, fig. 2.)

An excellent photographic view of the Concannon trench is given in Pl. III. It was made by Dr. H. M. Baum from a point on the bank of the little stream that passes out to the river bottom at this point. The entrance to the cellar tunnel is well marked by the figure of a lady near the center of the picture. The point of view is so low that the promontory which rises behind the terrace does not appear. The trench made by the Bureau entered the bench a few feet beyond the gate seen in the picture.

The cellar tunnel enters the north face of the bench near the base (*b*, figs. 1 and 2). The skull was found at *c*, 70 feet from the entrance, 20 feet from the upper surface of the terrace, and about 18 inches above the floor of the tunnel. The lateral trench is indicated at *d* in both illustrations.

The deposits composing the bench, so far as exposed, rest on the nearly level surface of a stratum of Carboniferous limestone (*e–e*), and the tunnel is dug so that this surface forms its floor. The deposits are believed by some to be true alluvial loess, derived directly from the ice front in the valleys above; they would thus represent one of the Glacial stages. Others regard them as consisting of finely comminuted material derived from the loess beds of the neighboring slopes and of other coarser materials from the hillsides spread out in comparatively recent times by local agencies in and about the entrance to the little valley. The first of these views has been adopted by Prof. S. W. Williston, Mr. Warren Upham, and Prof. N. H. Winchell; and the second is held by Prof. T. C. Chamberlin, Prof. R. D. Salisbury, and Dr.



FIG. 2.—Section of the Lansing site showing bluffs and river beyond, looking south. (*a*, Concannon dwelling and point of contact of limestone river bluff and recent bench. *b*, Entrance to cellar tunnel. *c*, Inner end of tunnel where skull was found. *d*, Trench opened by Bureau of American Ethnology. *e–e*, Outcrop of limestone in rivulet bed. *f*, Entrance of rivulet to Missouri River flood plain. *s*, Grade of stream bed.)

Samuel Calvin. I am inclined to favor this latter view, not only because it appears to be sustained by the geological evidence, but because it is in harmony with what we already know of the history of man in America. The skull corresponds in type with crania of the historic occupants of the region—the Indian tribes—which fact carries with it, according to the view of some biologists, a presumption against its great antiquity; and again, there is as yet no substantial and unequivocal evidence that men of any race existed in America during the Glacial period.

The geological features of the site, in so far as they relate to the question of human occupancy, may be briefly reviewed and their interpretation may be presented in the same connection. The first step in the history of the site requiring attention is the exposure or partial exposure of the nearly level limestone floor on which the materials of



SITE OF CONCANNON HOUSE AND THE TERRACE WHERE LANSING SKULL WAS FOUND.

Skull found 20 feet deep in terrace, 70 feet in, at a point in front of house, little to left of braced fence post. Woman with white waist is at mouth of tunnel. The Bureau trench enters terrace just beyond gate. Photograph by Rev. Henry Mason Baum.

the Concannon bench were afterwards deposited. This probably took place when the river channel curved sharply in against the bluffs at this point, permitting the currents to break down and partially remove the superior beds of shale and limestone well within the entrance to the little valley. When this active erosion ceased the limestone surface was strewn with rocky débris a foot or two deep, and in against the bluff at the southern margin there were heaps of coarse talus material upon which the two human bodies were cast or in which they were rudely buried; and just here we reach the point of divergence of the two interpretations with respect to the period at which these events occurred. The first view assumes that we are probably dealing with the Iowan epoch of the Glacial period. If this is correct, the events following the deposition of the bodies would be about as follows: During this period the river, becoming burdened with silt from the receding ice front, buried the bodies and began to fill up its channel. Step by step the surface rose until the immediate valley was filled and obliterated and the waters flowed out over the highest bluffs, depositing everywhere the mantle of silt known to geologists as loess. As the ice receded to the far north deposition gradually ceased in this part of the valley, and the river, step by step, cut its way down again through the vast deposits that filled its former channel, leaving a succession of loess terraces more or less well defined against the hillsides, and finally, after many fluctuations, reaching its present level, which at extreme high water is from 5 to 10 feet lower than our datum level—the limestone floor indicated at *e–e*, fig. 2.

But are we warranted in supposing that the two human bodies became associated with the débris on the limestone floor during this great epoch in glacial history, or are we to adopt the opposing view that at the end of this episode, or long after its close, when the river had descended to nearly its present level, the floods uncovered the limestone surface within the entrance to the little valley, and that at this time the aborigines, the ancestors of our historic tribes, left their dead among the heaps of débris?

The latter view assumes that the river probably had little to do, directly, with depositing the materials that buried the human bodies and now form the Concannon bench; that after clearing the limestone floor the current probably followed its habit of rapid change and shifted for a time to the eastern side of the broad flood-plain, leaving other agencies to control the destinies of the little valley now occupied by the Concannon farm. Naturally, the deposits of the bench have been examined with minutest care with the view of determining the story of their accumulation. If laid down in water they should show decided evidence of assortment and bedding; if the result of redistribution of loess and other local materials through surface agencies, the deposits would present little evidence of assortment and

no evidence of systematic stratification. Throughout the entire depth of these formations, as exposed in the tunnel and in the trench, there appears to be but one feature that can be construed as giving decided support to the view which favors fluvial origin. A thin seam of clay appears in the west wall of the tunnel, some 3 feet above the limestone floor, and extends from the entrance far back toward the south, rising at a low angle. The earlier examinations of this deposit led to the conclusion that the lower part, at least, of the formation had been laid down by the river, but subsequent investigations show that the layer is not continuous, that it is not found in the east wall of the tunnel opposite its appearance on the west side, and that it pinches out quickly to the west, no trace of it having been discovered in the walls of the great trench dug by the Bureau. It is just such a layer of water-laid clay as would accumulate in the bed of a sluggish stream running with the trend of the tunnel at this point, or through the presence of a small oblong pool of water left during a season of flood before the river finally deserted this level.

The deposit is composed for the most part of loess-like silt, through which, at all levels, are scattered fragments of limestone and shale, the whole presenting much variety of composition and irregularity of accumulation; hence it is surmised that the history of its deposition may be somewhat as follows: When at a period indefinitely later than the close of the Iowan epoch, and possibly much later than even the close of the Glacial period, the river retreated from the west side of the valley, leaving the limestone floor at the entrance to the little valley freshly exposed, the steep slopes of the valley, half a square mile in area, were mantled with loess deposits, and these, with coarser materials from the general surface, were carried down by creep and wash to the gateway of the little valley, where, since active erosion by the river had ceased, they accumulated, burying the exposed rock surface and the human remains to a depth of 20 feet or more and spreading out in a fan-shaped delta on the river flood-plain about the mouth of the valley. The narrow entrance to the valley probably favored accumulation, and the weak intermittent rivulet must have been quite incapable of clearing the way and carrying the accumulated material far out over the plain to the river channel. At any rate it seems altogether reasonable to suppose that 20 feet or more in depth of this material could have been deposited within and about the entrance to the little valley. The amount of accumulation would be limited only by the length of time that the river channel remained far away to the east and by the supply of easily eroded material. It is readily understood, however, that between the period of the burial of the human bodies and the present time the river may have returned once or several times toward the west bluff, permitting active work in undermining and cutting down the limestone face. That it did return

is strongly suggested by the apparent recentness of the cutting and the fact that the Concannon bench, the surface of which was at one time continuous with the flood-plain surface, is truncated on the face uniformly with the main bluff. This return of the channel to the west side would give the little stream the opportunity of lowering its channel to the present perfect adjustment with the river, and especially so since, as the centuries passed, the loess deposits had been largely removed from the slopes of the valley above and rapid accumulation about its mouth by creep and wash had necessarily ceased.

The preferred interpretation of the phenomena, then, is that the relic-bearing deposits of the Concannon bench were not laid down in Glacial times by the silt-charged waters of the Missouri, but that they are a remnant of delta-like accumulations formed in comparatively recent times within and about the mouth of the tributary valley by local subaerial agencies, all save the more protected portions having been removed by late encroachments of the ever-changing river.

The time involved would not be that required by the Missouri to lower its flood plain from the upper level of the bench to the present high-water mark, a descent of 30 or 35 feet, but the period required to depress the flood plain from a little above the surface of the limestone floor on which the bodies rested to its present level, a descent of from 5 to 10 feet. The measure of this amount of erosion in years is the measure of the age of the Lansing man; this may be thousands of years, but at most it can be but a fraction of the time required by the other view, for, according to that view, the river, after burying the human bodies, filled its channel with glacial deposits until it overflowed the highest bluffs, and then descended again to the present level. The time required to fill up the valley, 3 or more miles in width and nearly 200 feet in depth, and then to cut this filling all out again can never be determined, since chronologic criteria are largely wanting; but it might well reach ten, twenty, or even thirty thousand years. On the other hand, the time required by the river to lower its bed 5 or 10 feet might possibly be expressed in hundreds rather than in thousands of years. It may be of importance to note, however, that even this amount of lowering need not be assumed in accounting for the facts. The high-water mark to-day along the Concannon bluff, with the river a mile or two away across a wooded plain, might well be several feet lower than the highest level reached by a strong current driven directly or even obliquely against the bluff.

The anthropologist may readily find other than purely geological criteria to aid him in reaching his conclusions. It is a part of our common knowledge that men have occupied the American continent for a long period, but that they occupied it during the Glacial epoch, or even at the period when the Glacial front finally receded northward, is not demonstrated. Besides, as already mentioned, the cranium is

well preserved and fresh looking, and is nearly identical with crania of our historic tribes. Now when, as in the present case, two somewhat equally supported interpretations of the geological phenomena are possible—the one making it appear that remains of men occur in formations where they could reasonably be expected, and the other carrying human occupancy back ten thousand or twenty thousand years—the anthropologist may consistently accept, tentatively at least, the first of these interpretations, and the non-professional student of the subject may find it wise to at least withhold his full acceptance of either view until those geologists best qualified to discuss the special problems involved shall have reached practical unanimity.

As a result of my own observations at Lansing, and considering also the conclusions reached by Professor Chamberlin and his associates, I find it difficult to come to any other conclusion than that the human remains under consideration are properly classed as of Post-Glacial age, interpreting that term to cover all time subsequent to the final retreat of the ice from the region south of the Great Lakes.

The Lansing skull, illustrated in Plates I–II, belongs to Mr. M. C. Long, curator of the Kansas City Museum. It has been carefully repaired under the direction of Dr. George A. Dorsey, and is now deposited in the United States National Museum.

THE WILD TRIBES OF THE MALAY PENINSULA.[a]

By W. W. Skeat, M. A.[b]

In addition to the civilized brown-skinned Muhammadan Malays, who are a distant offshoot of the Mongolian stock, there are at least three groups of savage and heathen tribes in the Malay Peninsula, which may be roughly distinguished as follows, according to the character of their hair:

1. Woolly-haired Negrito tribes, called Semang.
2. Wavy-haired tribes, called Sakai.
3. Straight-haired tribes, called Jakun.[c]

Of these, the Negritos (Semang) are found in northern Pērak, Kedah, Kĕlantan, Trengganu, and the northern districts of Pahang (Pl. I, 1); the Sakai in southern Perak, Selangor, and Pahang (Pl. I, 2), and the Jakuns (mixed with other tribes) in all districts south of the States mentioned down to Johor and Singapore, and also, generally speaking, along the coasts (Pl. I, 3).

The first of these groups—the Semang—is a fairly pure branch of the Negrito race, which includes the natives of the Andaman Islands, in the Bay of Bengal; the Negritos, of the Philippine Islands, in the China Sea, north of Borneo, and the Semang, of Malaya.

A curious point about this group is that it still remains a moot question—as our most recent authorities declare—whether any Negritos occur in Borneo, which would naturally be the connecting link between the Malay Peninsula and the Philippines.

Some day it may be possible to answer this question, but meanwhile it is no less difficult to say who the Negritos really are. They seem to have received their name from the Spaniards, who regarded them as a sort of dwarf negro race, although they have nothing in common with the true Negroes but their woolly hair and black skin. The old idea

[a] Reprinted, by permission of the author and publisher, from Journal of the Anthropological Institute of Great Britain and Ireland, Vol. XXXII, January–June, 1902, pp. 124–138.

[b] Presented to the Institute February 11, 1902.

[c] This classification is practically based upon that of Prof. Rudolf Martin, of Zurich, who for some years past has been preparing an important monograph on the very difficult anthropology of these tribes. It differs solely in the isolation of the third (Jakun) type, which is included in Martin's third group under the heading of "Mixed tribes."

seems to have been that they were the offspring of African negroes who had escaped from slave dhows which had been wrecked in the Eastern Archipelago; indeed, I have heard of one widely recognized authority who maintained that the Negritos were the descendants of African slaves brought over by Alexander the Great when he visited India.

Nowadays, however, anthropology takes a more sober view of racial relationships, and it is pretty generally acknowledged that the Negritos are not Negroes, nor even a branch of the Melanesian or Papuan race, as others have held, although, if there is to be guessing, the hypothesis that would appear to have the most likelihood of being some day substantiated is the brilliant suggestion of Sir William Flower, who thought that the Negritos might possibly represent an infantile type of a woolly-haired race, of which the Negro on the one hand and the Papuan on the other were highly specialized derivatives. Even this, however, as I have said, is but guesswork, and for our present purposes we must be content to regard the Negro, the Negrito, and the Papuan as the representatives of three very different and separate racial types.

It may perhaps be of interest to add that for many years, perhaps on account of the tree-dwelling habits of some of these tribes, it was hoped that the Semang might possess some ape-like attributes. Though these expectations have been shattered, and the Semang can not henceforth be regarded as possessing an abnormally pithecoid character, he still retains the interest which attaches to him as a representative of one of the wildest races of mankind now extant.

The second type of which these races are composed is represented by the Sakai tribes, who offer, if possible, a yet more difficult problem. An attempt has recently been made to identify them, mainly, it seems, on the strength of linguistic evidence, with what is called the Mon-Annam group of races, i. e., with the tribes who possessed till about six hundred years ago the country which is now Siam, and some of whom still occupy Pegu and Camboja.

Linguistic evidence has, however, repeatedly proved a blind guide in the elucidation of racial problems, and I do not think we can depend upon it in the present case. Racial classifications must be based on racial facts, and in the present case we have the more credable alternative suggested by Professor Virchow for what appears to be a very different grouping.

Virchow's theory is simply that the Sakai may quite possibly belong to what he calls the Dravido-Australian race, the chief representatives of which are the Veddas or wild tribes of Ceylon, the civilized Tamils of southern India, the Australian black fellows, and the Sakai of the Malay Peninsula.

In the essential characters of the hair and head, there is certainly a remarkable agreement, and the only great difficulty about this grouping seems to arise from the color of the skin, which among the Sakais



FIG. 1.—SEMANG (PANGAN) OF K. ARING ON LEBIH RIVER, ULU VULANTAN, EAST COAST.



FIG. 2.—SAKAI TYPE.

Photograph by Rudolf Martin

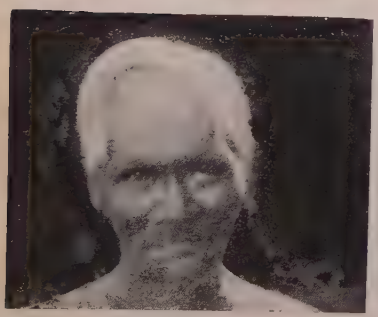


FIG. 3.—JAKUN TYPE.

Photograph by D. Machado.

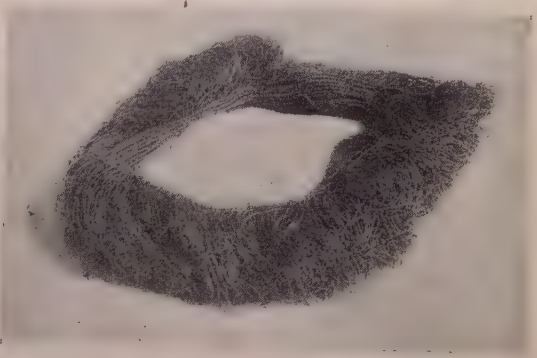


FIG. 4.—SEMANG GIRDLE MADE FROM RHIZOMORPH OF FUNGUS (KEDAH).



FIG. 5.—DANCE WAND, FLUTE, AND NOSE FLUTE.



FIG. 1.—SEMANG WITH SHAVED HEADS, ULU PERAK.

By F. W. Douglas.



FIG. 2.—MIXED SEMANG SAKAI TRIBE (ULU PAHANG).

Photograph by D. Machado.

often approaches a light shade of yellowish-brown, whereas among the Tamils black skins commonly occur. Professor Virchow meets this difficulty by pointing out that the Sinhalese of Ceylon, although admittedly Aryans, are frequently so dark in color as to be called quite black.

This point let authorities decide; all that can be said at present is that it appears an eminently sane and arguable hypothesis; and that it seems to have already found some acceptance. If it is correct, we may perhaps suppose that these aboriginal Dravidians once extended far north into Indo-China and there acquired the dialects of the local (Mon-Annam) tribes, an idea about which there is at least nothing fantastic.

The third racial group to which I have referred consists of the Jakuns, an aboriginal race closely related to the Malay, and which, in its pure type, possesses markedly Mongolian features. They belong to what the Germans would call the "Ur-Malay" race, but which we, in the absence of any such convenient prefix, are constrained to call by some such clumsy substitute as Præ-Malay or Proto-Malay—the "savage Malays" of Alfred Russell Wallace. The simplest name to give them is perhaps "Malayan."

This "savage Malay" or Jakun race, or whatever we prefer to call it, is divided into two main groups, (1) the Jakuns of the Jungle, or Hill Jakuns, and (2) the Jakuns of the Sea, or Orang Laut. The latter set of tribes now consist of the broken remnants of the Pirates or Sea-gypsies of the Straits of Malacca, who for so many years were the scourge and terror of those far eastern seas.

From what I have said it will, I think, be evident how important are the issues which may depend for solution upon our proper study of these tribes. Before closing these notes on the general relationship between these three races and their neighbors, I will therefore give a few more details concerning each of the several types described.

The physical contrast between all three races is most fortunately sharply drawn.

The men of the first-mentioned race (Semang or Negritos) are about 4 feet 9 or 10 inches in height, their women being about 3½ inches shorter. The color of their skin is very dark brown or black. Among the purest-bred Semangs I have seen it a glossy jet black, not unlike the color ascribed to the Andamanese, viz, that of a newly black-leaded stove. The shape of the head is mesaticephalic and brachycephalic (i. e., either rounded or intermediate between the long and round types). The forehead is low and rounded and projects over the root of the nose, which is short and depressed and pyramid shaped. The eyes are round and wide open and show no trace of obliquity, the iris being of a very rich deep-brown color. The lips vary from moderate to full, the mouth is rather large, the chin but feebly developed,

and a side view of the face sometimes shows some prognathism or projection of the lower part of the facial area.

The hair is of a very dark brownish black (never blue black, as among Chinese and Malays). It grows in short spiral tufts, curling closely all over the scalp, if not shaved off, as it very frequently is.

The height of the Sakai does not materially differ from that of the Semang,[a] but the color of the skin is very much lighter than that of the Negritos, and sometimes shows a reddish tinge about the breast and extremities. The head is dolichocephalic, or long shaped. The face is inclined to be long, and would be hatchet shaped but for the breadth of the cheek bones, which help to give it rather an elliptical outline. The chin is commonly long and pointed; the forehead rather high and flat, but brows often beetling, the notch above the nose being very deep; the nose small, often slightly tilted or rounded off at the tip, but at the same time broad and with very deep-set nostrils. The beard usually consists of a few long and frizzly chin hairs, remarkably like that of the Veddas of Ceylon, but in some cases it certainly grows long and bushy.

The third class (the savage Malays or Jakuns) is hard to identify, as it has received a large admixture of Semang and Sakai blood. Nevertheless, the pure type is, I think, recognizable and will be found to differ widely from both of the two types already mentioned.

They (the Jakuns) are a little taller than the Sakais or Semangs. Their head is brachycephalic or rounded, their skin olive brown to dark copper. Their face has a flattened appearance, and their lower jaw is inclined to be square. Their nose is somewhat stumpy—i. e., thick and short—but with wide-open nostrils. Their cheek bones are high and well marked, like those of the Malays and Chinese. Their eyes are black and of moderate size. Their mouth is large and broad. Their hair straight or lank, and with a bluish-black tinge to it, not unlike that of the Malays themselves. Their beard is scanty.

In addition to the foregoing three main types we have perhaps naturally, in spite of their antagonistic elements, a good many instances of mixed tribes, most of which can, if the purest types be taken as standards, be resolved with a fair amount of certainty into their original ingredients.

There are many physiological points about all these tribes which would be of great interest if I had time to go into them. Their arm stretch, for instance, is almost always greater, sometimes much greater, than their height. Their feet are unusually short and stumpy and splayed, with a remarkable inward curve of the great toe, the prehensile character of which enables them, when spoiled by domestication, to become very clever at stealing. I have seen Semangs run up trees by

[a] For the information about the Sakais (as well as for the type photograph) I am very deeply indebted to my friend Rudolf Martin.

placing the flat of the foot against the trunk and putting their arms a good way around it. The eyesight of the Sakais, as tested with the army tests, though not abnormal, is distinctly good and seems to compare very favorably with our own. The Jakun power of scent is exceptionally keen, and I was frequently astonished at the great distance at which they would notice the smoke of a camp fire in the jungle many minutes before I could detect the least trace of smoke myself. Their walk is very peculiar, the foot being lifted very high, almost as in dancing, and by this, and a certain restless expression about the eyes, even those Jakuns whose features are most like those of the Malays, can be immediately distinguished when they are met crossing open country.

The food of these jungle tribes—their first and most vital consideration—consists mainly of vegetable products, such as the roots and fruits which they dig up in the jungle, as well as (among tribes who have reached the first stage of agriculture) of the product of light crops, such as yams, sweet potatoes, maize, sugar cane, and bananas, and, at a later stage, of rice. Meat food, consisting of game brought down by the blowgun or the bow, is also largely employed for food, but this is mainly among the Semangs, some tribes of Sakais neglecting to go in pursuit of game until their supply of vegetable food is beginning to run out, though even among a good many Sakai tribes both hunting and trapping are energetically carried on. Some of the yams eaten are poisonous and require careful preparation to render them fit for human consumption; some kinds are buried for days together in a bag in the swamps of the jungle (or in running water), when they are dug up and have the juice squeezed out of them with a lever before being cooked and eaten; other kinds are grated on an ingenious natural grater made of the young growing shoot of a highly prickly rattan or calamus, the grated mass being kneaded with a spatula upon a banana leaf and mixed with slaked lime in order to destroy its poisonous properties, when it is wrapped up in a strip of green banana leaf, inserted in a split stick, and roasted over the fire. At meals the Semang men, from the oldest to the youngest, all feed together before the females, the latter, who have done the cooking, looking on with hungry eyes until their lords and masters have finished their repast.

In the matter of animal food both Sakais and Semangs eat everything that comes in their way—monkeys, deer, wild pig, birds, fish, porcupines, lizards, squirrels, rats, and mice; not even snakes are excepted from the menu, which, it will thus be seen, is a sufficiently varied one.

In hunting and trapping, which are employed solely for food purposes, these tribes are, as might be expected, exceedingly expert. They have a marvelous knowledge of the jungle and its inhabitants, and seem to have an instinctive knowledge of the presence of animals,

being able, when no one else can, to tell the exact whereabouts of a bird or animal moving a great way off in the forest. Their sight, as I have said, is naturally good, and through training becomes wonderfully quick. The same is true of their hearing, and, as they are believed to be able to track snakes by their smell, it is evident that that faculty is in no way inferior. They know their way about the jungle better than anyone, and their intimate knowledge of the life history of the jungle beasts is turned to account in the methods by which they hunt and trap their game.

HUNTING AND TRAPPING.

The chief weapon of the Semang (as among Negrito tribes elsewhere) is the bow, which closely resembles that used in the Little Andamans,[a] and with which poisoned arrows are used. That of the Sakai and Jakun is the blowgun or blowpipe. This latter is commonly a long slender tube, often 6 or 8 feet long, composed (whenever so long a piece is obtainable) of a single joint or internode of an exceedingly rare species of bamboo, which is found in the peninsula on two or three high mountains only, and which is called Bambusa Wrayi.[b] This tube is protected and strengthened by being inserted in a similar bamboo tube or case of slightly larger caliber. The darts are made of fine slivers obtained from the midrib of the leaf of certain kinds of palm. They are about the size and thickness of a steel knitting needle, and are furnished at one end with a small, conical butt which is made to fit (rather loosely) the bore of the inner tube or blowpipe. The point is about an inch or more long and as sharp as a needle, and just above it a nick is cut in the shaft of the dart, which causes the point to break off in the wound when the quarry attempts to escape through the tangled undergrowth. The point is, moreover, thickly coated with poison compounded from some of the most deadly poisons known, among which are the sap of the well-known Upas tree (*Antiaris toxicaria*) and the sap of a shrub called Ipoh Akar, which is a species of Strychnos.

The blowpipe is a breechloader, the dart being inserted in the orifice, with a light wad of a fluffy substance obtained from the leaf bases of a palm (*caryota*) packed behind the butt end for the prevention of "windage." It is shot by taking part or the whole of the mouthpiece into the mouth and sharply expelling the air from the lungs. The dart thus poisoned and ready to break off in the wound may in fact be not inaptly compared to the sting of a bee, from which it may quite possibly, to some extent, have been copied.

[a] E. H. Man, The Andaman Islanders.

[b] A very much rarer kind is the wooden blowgun of Kuantan, which is made by lashing together throughout their entire length two half cylinders of wood. One of these latter, measuring 5 feet 2 inches in length, has recently been presented to the British Museum by Mr. F. W. Douglas, of the F. M. S. service.

Even the blowpipe itself is not without its natural prototype in the Malay Peninsula, in the rivers of which there lives a small fish called *Toxotes jaculator*, which I have myself seen shoot a fly off a leaf several inches above the surface of the river by means of a small drop of water forcibly expelled from its mouth.

By the Sakais each of the darts is carried in a separate reed, about 30 to 50 of these reeds being lashed together, rolled up into a bundle, and fitted into an ornate bamboo quiver. The butt ends of the darts are frequently marked to distinguish the strength of the poison.

The Semang quiver contains fewer darts than that of the Sakai, and is without reed bundle, cap, or rings; in fact, it is a mere internode or joint of bamboo which is only remarkable for the beauty of the designs with which it is decorated. Various compounds of the two main poisons to which I have referred are used by the wild tribes, the ingredients varying according to the fancy of the maker. Thus, venom from the fangs of serpents, centipedes, scorpions' stings, etc., is frequently added, though it is in no way really required. Furnished with these darts, both Sakais and Semangs regularly bring down their quarry at short distances up to about 30 paces, and have even been known to kill birds and monkeys on high trees at a distance of 60 yards. The method of collecting and applying the coat of poison to the dart point in its simplest form is as follows: The bark of the tree (when the tree poison is used) is slashed with a jungle knife in the shape of a big V. The poisonous sap, which immediately collects at the apex of the V, is then drawn off into a bamboo vessel and carried home, where it is either, when small quantities are used, as among the Semangs of Kedah, merely heated and applied to the dart points or prepared by boiling until a sufficient consistency is obtained. In the former case it is poured out into a bamboo tray and applied to a broad wooden spatula, which is heated over a fire until it begins to dry, when the point of the dart is rolled upon the spatula, the dart being then deposited against a fallen tree trunk to dry in the sun in a safe place. Among some Sakai and Jakun tribes an elaborate kind of drying rack is used, which prevents the darts, which are very light, from being carried away in a high wind while drying.

HABITATIONS.

The most primitive forms of dwelling employed by the wild tribes are rock shelters (sometimes caves, but more commonly natural shelters under overhanging rocks) and leaf shelters, which are sometimes formed on the ground, sometimes between the branches of trees. The simplest form of these leaf shelters consists of a single big palm leaf, which is planted in the ground to afford the wanderer some slight shelter for a single night. The more elaborate leaf shelters, used especially by Semangs, sometimes take the form of a rude lean-to,

consisting of three or four uprights planted in the ground at an angle of about 60° to 70°, with palm leaves or branches lashed horizontally across them. Other kinds consist of palm leaves planted in the ground in the form of a semicircle or circle, the leaves, which are frequently about 6 feet long, drooping over toward the center, and thus forming a shelter of the circular or beehive type. The most developed form is a long communal leaf shelter in which all the members of the tribe reside.

The Malayizing tribes who come more into contact with civilization insensibly adopt the Malay type of hut, but even here some striking departures from the normal Malay type are to be seen, e. g., in the low or almost totally absent side walls and in the projection of one side of the gable over the other, so as to allow the roof to remain open at the top. These huts are generally barricaded with fallen trees.

The tree huts or "human bird nests," as they have been called, are built at a height of from 20 to 30 feet from the ground, chiefly as a means of escape from wild elephants.

ARTS AND CRAFTS.

The craftsmanship of these wild tribes, though extremely primitive, is excellent of its kind, and shows that they by no means lack ingenuity.

The manufacture of the blowpipe, its darts and quiver, as already described, forms an important industry of both Semang and Sakai. The tree-bark cloth of the wilder tribes is made by hammering (with a wooden mallet) the bark of a big jungle tree called Terap (*Artocarpus Kunstleri*, a species of wild breadfruit tree), the outer surface of which is first removed by scraping it with a knife. The mallet is frequently improved by transverse grooves or teeth, which assist in the separation of the fibers.

A not less interesting type of cloth is manufactured from the cuticle of the Upas tree (*Antiaris*) itself, a tree which belongs, I believe, to the same order as the Artocarpus. In this case a young sapling (of the Upas tree) is felled and a ring cut round the bark a few feet from the base. The bark is then scraped and pounded in situ with a rounded wooden mallet or club for a space of about a foot below the incision. The pounded part is then pulled away from the stem, separating at the point where the bark meets the wood, and is turned down (not rolled) and skinned off like a stocking, the scraping and pounding being continued at intervals, as required, until all the bark is completely separated.

As regards other forms of industry, mat work, basket work, and netting, are all found among these tribes, but no kind of weaving or pottery whatever. A high artistic sense is, however, shown (by the

Semang especially) in the beautiful and finely executed designs with which they decorate their blowpipes and quivers, and the magic combs worn by the women. An amusing example of the skill of the Jakuns was furnished me in the form of a set piece, representing the use of the blowpipe.

DRESS.

The commonest form of clothing worn by the men of all these tribes is the waistcloth of tree bark, which consists of a long narrow strip of hammered bark. That of the women, on the other hand, is usually a sort of short petticoat or wrapper of the same material. But the most interesting form of girdle worn by these tribes is undoubtedly one which is beautifully woven from the long, black, shining strings or cords called rhizomorphs, which are in reality the vegetative parts of a toadstool. (Pl. I, 4.)

Leaving the question of girdles, there are several other slight, but otherwise important items of attire worn by these tribes, such as arm bands, necklaces, and combs. Arm bands and even leg bands are frequently worn, apparently for the purpose of bandaging and so strengthening the muscles. They vary from a simple tie of jungle fiber to metal circlets or spirals, which latter are usually obtained from the Malays.

The necklaces, which are worn chiefly by the women, it would appear mainly for magical purposes, consist at times of as many as nine strings, and are composed of such objects as monkeys' teeth, tufts of hair from squirrels' tails, black and white beads, seeds of jungle fruits, shells, etc.

The combs, which bear magical designs, and are worn solely by women, are of the kind which I believe are termed back combs in England, but which are only worn to defend the wearer against poison or sickness. To complete the picture, tattooing or rather scarification is practiced over a limited area among the wilder tribes of the interior, with face and body painting (apparently as a substitute for tattooing) in places where Malay influence has begun to enter. The usual pattern consists of four or five horizontal stripes on the cheeks, with a sort of trident or pitchfork design on the forehead or chin. For the stripes on the cheeks are often substituted rows of black and white dots, supposed to represent what are called the spores, or perhaps more correctly the sori, of a fern. The tattooing is performed by drawing the finely serrated edge of a sugar-cane leaf across the skin and rubbing into it powdered charcoal.

In addition to the foregoing the septum of the nose is frequently (among the Semang and Sakai only) pierced to admit the quill of a porcupine, bone, or piece of stick, or some other decorative object of the kind.

MUSIC AND DANCING.

It would take too long to describe in any sort of detail the musical instruments of these tribes. Suffice it to say that they are almost always made of bamboo, some of the most primitive kinds being of special ethnographical interest, notably the bamboo jews-harp and the nose flute. One or two of these latter (Pl. I, 5) may be played at a time, the performer breathing into the mouth hole of the flute through the nostrils. This instrument is found among tribes who do not use the blowgun, as well as among those tribes who do, but the accomplishment should be an easier one for the latter, i. e., the Sakais, to acquire, from the healthy development of the lungs with the blowpipe exercise. Simpler forms of instruments are represented by a couple of sticks which are struck together, producing a sound like castagnettes, and (among the Semang) by big internodes or "joints" of bamboo, which are closed naturally by the node at the lower end and played by being beaten at the upper end with a fan-shaped palm-leaf beater.

The most important instrument of the Jakuns is the drum, which is made of a hollowed-out trunk of screw pine, headed with the dressed skins of mouse deer or monkeys.

On festive occasions, e. g., for singing and dancing, both sexes decorate the person profusely with festoons of leaves. The Sakais and Jakuns in addition wear upon the head a curious circlet made of strips of palm-leaf (licuala) in the form of a plait with long streamers so depending from it as partially to conceal the face of the dancer. That of the woman has in addition a number of short sticks on which are spitted fragrant leaves or flowers, on a principle of which we seem to have the counterpart in the design of some of our peers' coronets. In the girdle, head-band, and festoons (which are crossed upon back and breast) are inserted bunches or bouquets of cunningly woven strips of palm-leaf representing nooses, etc., which are said to be intended to entrap evil spirits when they make assault upon the person of the dancer.

Finally a short wand or scepter is carried, which takes at times a most peculiar shape, resembling a series of crescents and double axes. (Pl. I, 5.)

FEASTS AND SONGS.

In former days at harvest time the Jakuns kept an annual festival, at which, the entire settlement having been called together, fermented liquor brewed from jungle fruits was drunk; and to the accompaniment of strains of their rude and incondite music, both sexes, crowning themselves with fragrant leaves and flowers, indulged in bouts of singing and dancing, which grew gradually wilder throughout the night, and terminated in a strange kind of sexual orgie.

The songs which were sung on these occasions were sometimes merely topographical, but more often the theme was a description of

some one of the denizens or products of the jungle. Commencing by setting forth the attributes and habits of some particular wild animal; or bird, they would proceed to describe the incidents of its pursuit by men from their encampment, its death by a venomed shaft from the blowgun, the return of the successful huntsmen, and the impartial division of the spoil. It has often been said that these songs are mere gibberish and have no connected meaning. Whether they are so or not, the following extracts will show.

The first is one of the Semang songs which I took down in Kedah. It refers to a kind of long-tailed monkey called "kra," whose name forms the burden of the song.

"He runs along the branches, the kra,
Carrying fruit with him, the kra,
He walks to and fro, the kra,
Over the knotted 'seraya' tree, the kra,
Over the knotted 'rambutan' tree, the kra,
Over the live bamboos, the kra,
Over the dead bamboos, the kra,
Over the giant bamboos, the kra,
He hangs downwards, the kra,
And runs along the branches, the kra,
He runs along and hoots, the kra,
And peers forward, the kra,
Among the young rambutans, the kra,
And shows his grinning teeth, the kra,
From every sapling, the kra!"

Here is one of the Jakun songs, which is one out of a set of about thirty different ones which I took down in Selangor:

"'Impit-impit' is the cry of the rhinoceros,
The rhinoceros of the herd (calling) to the recluse rhinoceros,
He calls his comrades to seek for food.
He walks the forest and climbs the hills.
He walks abroad when the dew dries on the granite.
What skills it for me to resist the rhinoceros?
I call my comrades, but my comrades are not there.
I am terrified and climb up into a tree,
But the rhinoceros waits at the tree's foot.
I break off a bow and throw it down to him,
The rhinoceros champs it, and passes onward.
I climb down to ground again and run back homewards
And climb into the hut, but the rhinoceros follows.
I take my gun and shoot the rhinoceros.
The bullet has hit him! The rhinoceros has fallen!
I roast him next and cut up the rhinoceros,
And give of the meat a little to everyone.
But the horn I sell to the Chinese foreigners."

Other songs in my collections describe the tiger, elephant, bear, crocodile, birds and bats, fish, various reptiles, and fruit. A very pretty one is about children bathing.

MARRIAGE.

Marriage, among all these tribes, is said to be based on purchase. Of the actual ceremonies the most interesting is the form of wedding rite which is usually described as the ant-heap ceremony. The bridegroom is required to overtake the bride before she has run seven times round the ant-heap, and in the event of his failing to do so the marriage has to be postponed for a future occasion.

This is the usual account given by people who have recorded it from hearsay. I was, however, on one occasion fortunate enough to be present at one of these weddings, and I then discovered that the orthodox object round which the chasing took place was not really an ant heap, but a small artificial mound, the cause of the confusion being the use of the Malay word Busut, which may bear either meaning. The artificial mound (fig. 3) which was used on this occasion was about 3½ feet high with about the same diameter at the base. Its shape was that of a truncated cone, surmounted by a small globe and knob. It resembled not remotely a gigantic bell and bell handle. It was decorated with jungle flowers, and the Jakun chiefs assured me that this was the "genuine article," and that it was the emblem of their religion, and I see no reason for doubting the statement.

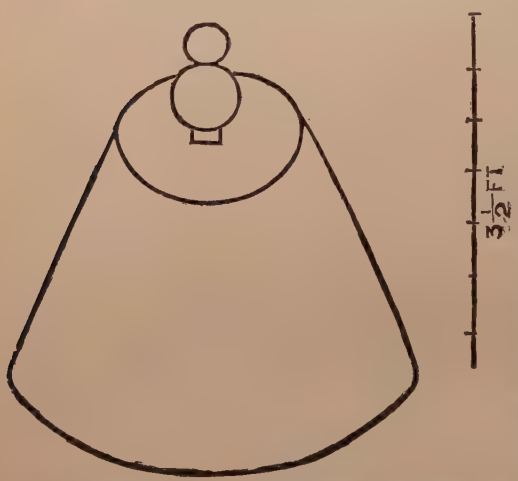


FIG. 3.—Busut or artificial mound of clay round which the bride is chased by the bridegroom. (Besisi tribe.)

Before the pursuit of the bride takes place the man or his proxy is subjected to a severe catechism by the woman's representatives, the questions asked being of a most searching description, e. g.:

"Can you fell trees?
"Can you climb for fruit?
"Can you find turtles' eggs?
"Are you clever at using the blowpipe? and
"Can you smoke cigarettes?"

This last query doubtless relates to the fact that the ceremony sometimes concludes with the smoking of a cigarette jointly by bride and bridegroom.

Among the Orang-Laut or sea gypsies the pursuit sometimes takes the form of a canoe race, in which the woman is given a good start, and must be overtaken by the man before she has gone a certain distance.

FUNERAL.

At a Sakai or Jakun funeral the body of the deceased is slung from a pole and carried to a distant spot in the jungle at least a cock's crow from the nearest house. Here it is wrapped in a new cloth and buried in a shallow trench, the clothes worn during the life of the deceased being burned in a fire which is lighted near the grave. The grave being filled up, rice is sown upon it and watered, some herbs and young bananas, etc., are planted round it (all of these being for the deceased's soul to feed upon), and finally a small three-cornered hutch, not unlike a doll's house, but raised on very high posts, is erected near the foot of the grave for the soul to reside in. The soul's house itself is about a foot and a half high, is thatched with palm leaves, and provided with a ladder for the soul to climb up by. It contains in addition diminutive emblems of the sex of the deceased (in the case of a man, the model of a hatchet and a jungle knife, etc.; in the case of a woman, the model of a back basket or wallet, such as is carried by the women of the tribe), as well as a supply of food (a little rice and fish, etc.) for the deceased's soul to feed upon, tobacco for it to smoke, and betel leaf for it to chew.

The Semang, on the other hand, practice a simple form of interment, a supply of food and drink being placed in the grave along with the body. There is, however, a tradition that they used to devour their dead and bury the head only, and although this assertion is certainly untrue now, and probably always was so, it is more than probable that like their close kinsmen the Andamanese they may once have been in the habit of disinterring the bones of their dead and breaking them into short segments to string on to their necklaces, in which case the skull may have once been worn, as among the Andamanese, as a sort of pendant attached to the necklace.

MAGIC.

The chiefs of the tribe were often, if not always, medicine men or magicians, their power in this respect being greatly feared by the Malays, who believed them to be capable of slaying people at a distance by means of what are called "sendings," which were small slivers of bamboo apparently representing darts, which being placed on the palm of the hand would (it was thought), at the magician's bidding, fly through space until they reached their intended victim, whom they would pierce to the heart and kill even at a distance of two or three days' journey.

The Buluh Pĕrindu or "love and longing" bamboo was said to grow upon almost inaccessible mountain peaks. Slivers of this plant were formerly obtained from the Jakuns by the members of Malay traveling theatrical troupes, who inserted them between the teeth,

this being believed to render the voice of the wearer irresistible. This custom, however, led, it was said, to such abuses that formerly in some parts of the peninsula the possession of any portion of the "Buluh Pĕrindu" was punished with the death penalty.

The chinduai or chingkuai is a small fragrant plant with minute inflorescences (sometimes it is described as a small white five-petaled blossom) which is believed to be one of the rarest and most fragrant flowers in the world.

The story goes that it formerly grew underneath a ledge of overhanging rock on one of the crags of the Ulu Klang mountains. Although the exact spot where it grew could be seen from the ledge, it was nevertheless inaccessible, and it was said that the wild man who wanted it had to ascend the mountain and there keep his fast possibly for weeks or months upon the summit of this ledge until a kite, which used the chinduai as medicine for its young, should drop a piece in flying over him. Whatever may be the facts, this particular charm is well known in connection with the Klang country, and is alluded to in the local quatrain which says, "Set not your foot upon the Klang mountains; if you do you will suffer from their charm."

Both Semang and Sakai are great adepts at the exorcism of demons; and on one occasion I saw an apparently wonderful cure effected by this simple means, the patient being a woman belonging to one of the tribes of Semangs in Kedah. We were all sitting and talking quietly in the long communal leaf-shelter in which the tribe lived, when one of the women, who suffered at intervals from agonizing pains in the limbs, was seized with a sudden paroxysm (which made her scream with pain) and presently leaped to her feet and fled into the jungle. The remainder of her companions, who declared that she had gone into the jungle to die there, slipped out one by one after her, and I decided to follow them to see whether anything could be done. When I arrived I found the woman seated on the ground, while the chief, in his capacity of medicine man to the tribe, was digging away for dear life with a pointed stick to try and unearth the stump of a small sapling which grew near the spot. This he presently succeeded in doing, and on examining the root found what he pronounced to be clear evidence of the demon's recent presence in the curious pinching in of part of the root. He next took earth out of the hole and rubbed it over the patient's stomach and back, muttering charms as he did so, in order to induce the demon to return to the spot whence he had come. In a few minutes the woman began to get better, but as the demons were not yet quite done with, the chief proceeded to dig up the stump of another tree, this time a creeper, whose root proved in shape to bear some resemblance to a mandrake. He then repeated the former process, and chanted his incantations more vigorously than ever, at the

conclusion of which two of the men of the tribe who assisted him hurled away into the jungle the stems of two saplings which had been lying near the spot, in order, they said, to get rid of the demon's presence. By this time the woman had ceased her lamentations, and in about ten minutes' time was pronounced cured, after which she quietly returned to the encampment as if nothing had happened.

The whole performance was an excellent example of sympathetic magic or make-believe.

The most remarkable development, however, of the wild magician's alleged powers is connected with the "tiger man" beliefs, which are analogous to former European ideas about werewolves. One of the Semang men whom Mr. Laidlaw and I met at Ulu Aring, in Kelantan, had the reputation of being a notorious tiger man, or B'lian, and gave me some interesting information about the performance. "You go," he said, "a long way into the jungle" (usually, he added, into the next valley), "and there, when you are quite alone, you squat down upon your haunches, burn incense, and, making a trumpet of your hand, blow some of the smoke of the incense through it, at the level of your face, in three directions. You then repeat this process, holding your hand close to the ground; all you now have to say is, 'Yē chŏp' ('I am going abroad'), and presently your skin will change, the stripes will appear, your tail will fall down, and you will become a tiger. When you wish to return say, 'Yē wet' ('I am going home'), and you will presently return to your natural form." It sounds easy enough, and the only wonder was that one so seldom heard in that part of the world of the disappearance of an obnoxious rival or a scolding wife.

The most interesting point about this ceremony, however, is its apparent universality, for it is found, mutatis mutandis, in all parts of the globe. In passing, it may be noted that a small variety of ripping knife (*bĕladau*), shaped like a tiger's claw, and fitted with a hole in the haft to pass the finger through, is well known and used to this day both in the Malay Peninsula and Sumatra, in both of which countries the were-tiger belief is still held strongly.

RELIGION.

The religion of the wild tribes is a form of shamanism such as prevails in other parts of southeast Aasia. They believe in certain greater spirits, who may perhaps, when we have found out all about them, prove to be a sort of gods in the making. But they have, of course, nothing which exactly corresponds to our own idea of God, and the evidence on this subject is more than usually conflicting, owing to the extreme reticence and timidity of these wild men themselves, of whom it would be but little exaggeration to say that they were as wild as deer. Most of them believe that the soul shortly after death proceeds to a place called the Island of Fruits (the jungle man's idea of

a paradise), which they not unfrequently identify with the moon. To reach this island they are compelled to cross a boiling lake resembling a copper, by means of a narrow bridge formed of a fallen tree trunk, and the souls of the wicked, failing to accomplish this in safety, fall off the log into the lake, where they swim about desperately for three long years, clutching at the smooth sides of the lake, after which the chief of the Island of Fruit Trees, if he so thinks fit, contemptuously lets down to them one of his feet so that they may catch hold of his great toe, in which undignified fashion they are at length permitted to escape from purgatory and to enter paradise.

THE PYGMIES OF THE GREAT CONGO FOREST.[a]

By Sir Harry H. Johnston, G. C. M. G.

[In the recesses of the great Congo forest have been discovered two tribes of men, the most backward in their development from lower forms of all the savage races of the Dark Continent. The following article is an account of their appearance, modes of life and speech, together with some vastly suggestive theories of their descent from the prehistoric invaders of Africa from Asia.]

THE INFLUENCE OF A GREAT FOREST ON THE EVOLUTION OF MAN.

The great Congo forest of west-central Africa must undoubtedly be regarded as a very important factor in the past history of Africa. By "history" I do not mean the record of man's doings only, or of the progress of the civilized races of men, whose adventures chronicled by writing have narrowed the use of the word to records of the progress of humanity during, let us say, seven thousand years, a mere half minute in the hour of man's existence. For not only in the "prehistoric" movements of man, but also in the preceding migrations of great beasts and anthropoid apes has this mighty forest checked and deflected the distribution of species or received into its bosom hunted, defenseless forms, which have thus been enabled (as in the case of the Okapi) to linger on into the present day.

Before, therefore, I proceed further with my description of remarkable negro types which are to be found on the eastern limits of this forested region, it may be well if I define clearly the area of forested Africa at the present day. Roughly speaking, the whole basin of the Congo, the enormous area of relatively low-lying land (once possibly the site of inland seas or of an extension of the ocean), is a region of dense forest. On the southwest the forest stretches, with here and there a break, over to the upper waters of the Zambesi River, and on the northeast it overlaps the Nile watershed, the southwestern fringe of which is covered with forest that spreads uninterruptedly from the Congo. In countries to the east, and even here and there near the littoral of the Indian Ocean, patches of primeval forest exist which scarcely differ from that of the Congo. It is possible, therefore, that

[a] Reprinted by permission of Sir Harry H. Johnston and the publisher, from McClure's Magazine, February, 1902; modified, by permission of the author, by paragraphs from Volume II of The Uganda Protectorate, by Sir Harry H. Johnston. New York: Dodd, Mead & Co., 1902.

the whole of Africa south of the northern tropic may once have been one continuous primeval forest.

Certain regions, however, on the north and south and, above all in the eastern half of the continent, proved less capable, from conditions of soil or moisture, to support this growth of vegetation. In these regions the great mammals that invaded Africa during the Pliocene epoch, through southern Asia and Arabia, found less resistance to their progress and conditions, such as the growth of grasses, more favorable to the development of herbivores; while of course the great carnivorous animals could exist only where the big vegetarian beasts would thrive. The mighty forests still existed, however—existed possibly with small interruptions—right across the continent from west to east. They therefore received into their safe recesses the anthropoid apes and the more timid and defenseless mammals of large size, which in the more open country would have been completely exterminated. The anthropoid apes had no doubt been driven away from western Asia and southern Europe by their successful compeer and offshoot, man, who can have been the only serious enemy of these ancestors of the gorilla, chimpanzee, and orangutan.



Ape-like Mukonjo. Blackish skin.

Some long while after the scared chimpanzees and gorillas had found a secure refuge in the dense woods of West Central Africa the earliest types of humanity who had entered the Dark Continent were also pushed toward this gloomy forest by the inroads of superior tribes, and some of their descendants exist there at the present day.



Ape-like type, Munande. Yellowish skin.

THE ANCESTORS OF THE APE-LIKE MEN.

It may be assumed as the most probable of all the theories on the subject that the human type emerged from the ape somewhere in Asia, possibly in Southern Asia, inasmuch as the real missing link, Pithecanthropus erectus, has been discovered fossil in Java. In any case early man appears to have had an immense development in and around the Indian Peninsula, and possibly there or thereabouts developed the three main types which he exhibits at the present day—the Mongolian, the Caucasian, and the negro. The pressure of superior races drove the negro types out of Southern Asia eastward to the Andamans, Malacca, New Guinea, the Pacific Islands, and Tasmania, and westward across Baluchistan, Mesopotamia, and Arabia to Africa. * * *

Summing up the experiences of many African travelers, together with my own observations, I should venture to say that there is a prognathous beetling-browed, short-legged, long-armed "ape-like" type of negro, dwelling in pariah tribes or cropping up as reversionary individuals in a better-looking people, to be met with all down Central Africa, from the Bahr-al-Ghazal to the upper waters of the Zambezi and westward from the Mount Elgon and British East Africa to Portuguese Guinea. I have seen during my experience in British Central Africa very prognathous ape-like negroes coming from the regions roundabout the Congo-Zambezi watershed. They were slaves in Arab caravans. Messrs. Grogan and Sharp noticed this strange simian type between Lake Kivu and Lake Albert Edward, on the eastern edge of the Congo forest. Knowing nothing at the time of their observations in this respect, I was much struck on entering the countries west of Ruwenzori at the ape-like appearance of some of the negroes whom I encountered. These were ostensibly members of the Bakonjo or Baamba tribes on the western flanks of that snowy range, or they were pariahs dwelling by themselves on the fringe of the great Congo forest, west of the Semliki River. This ape-like type was generally known to the surrounding negroes as "Banande." Whenever I encountered a rather brutish individual in this part of the country, he always turned out to be a Munande, but I am not able to say that there was any definite ape-like tribe known as "Banande." On the contrary, whilst here and there prognathous short-legged individuals existed in separate communities in a pariah-like condition, very often they might be the offspring of Bakonjo, Babira, Baamba, Lendu, or Bambuba peoples, who, in their ordinary type, were decidedly not simian, but who may have mingled in times past with the lowest stratum of the aboriginal population, with the result that the ape-like still cropped up by occasional reversion. I should also observe that similar prognathous, long upper-lipped, short-legged negroes reappear, though in a less marked form, among the Bantu people on the western slopes of Mount Elgon, in the dense forests clothing the flanks of that huge extinct volcano. * * *



Pygmy woman, 4 feet 1½ inches in height.



Short-legged type of negro from Semliki forest (Mubvanuma).

So far I have given the result of a general impression on the eye of various travelers when I have spoken of these negroes in the forested regions and border lands of the Uganda Protectorate being "ape-like." But I should state that the skulls examined, the photographs of the physical appearance studied, the measurements of head and body analyzed do not enable scientific anthropologists to indorse the term "ape-like" which has been used by myself and others to describe these negroes of degraded aspect. They offer sufficient general resemblance to the forest Pygmy type to be classed with them, perhaps in a group which I have styled (for want of a better name) the "Pygmy-Prognathous." * * * The resemblance between the pygmies and these Banande would appear to be osteological. Outwardly there is no special likeness between the two groups. Further evidence may show that the ape-like type may crop up in any negro race, whereas there can be do doubt that the forest pygmies are a well-marked and distinct type of negro.

Even before the negro quitted Arabia to invade and occupy the greater part of Africa he may have developed a pygmy type, or have had a tendency to generate races of stunted stature. Remains which have been found in Sicily, in Sardinia, in Liguria, and the Pyrenees, including a curious little statuette fashioned by men of the Stone Age discovered in the last-named locality, hint at the possibility of men of this pygmy negro type having spread over part of Europe. It has been even suggested by more than one anthropologist of authority that a dwarf-negroid race may have at one time existed in northern Europe, and by an exaggeration in legend and story of their peculiar habits—habits strangely recalling the characteristics of the little dwarf people of the Congo of the present day—have given rise to the stories of kobolds, elves, sprites, gnomes, and fairies. Like some of the Bushmen (who are, however, an independent development or an arrested type of negro) who inhabited South Africa when it was first discovered by Europeans, and who still exist in the southwestern part of that continent, like the European and Asiatic races of the early Stone Age, these negro dwarfs in bleak or poorly forested regions no doubt lived in caves and holes, and the rapid manner in which they disappeared into these holes, together with their baboon-like adroitness in making themselves invisible in squatting immobility—a faculty remarkably present in the existing dwarfs of the Congo forest—gave rise to the belief in the existence of creatures allied to man who could assume at will invisibility. Traits in the character of the Congo dwarfs of the present day recall irresistibly the tricks of Puck, of Robin Goodfellow, of the gnomes and fairies of German and Celtic tradition. * * *

These people are not definitely organized into a tribe, but hang about the fringe of other communities They speak the languages or dia-

lects of the better-looking people who are nearest to them. Some of these ape-like men have skins of a dirty yellowish brown. The head hair is black and thick. Beard, mustache, and whiskers are fairly abundant. The eyes are deep set and the overhung brow ridge is extremely marked. The upper lip is long, and neither of the lips is so much everted as in the ordinary negro. The body is covered nearly all over by a fine yellowish down, not apparent at any great distance, but tending to accentuate the yellow appearance of the skin. There is great prognathism, and the chin is weak and retreating. They appear to be rather stupid, timid, and unintelligent. They live in very rude habitations of boughs and leaves and spend their time chiefly hunting and trapping small mammals. They also live a good deal on honey and bee grubs. It would seem, however, on the western flanks of Ruwenzori and in the forests northwest of the Semliki River as though superior races had occupied the country once given over to the ape-like type and had mixed with this inferior people, so that the ape-like physiognomy may crop out again and again in races whose average numbers exhibit a higher type of feature and figure.

THE DESCENDANTS OF THE PYGMIES OF HERODOTUS.

The Congo forest also shelters within its recesses at the present day those curious pygmy negroes who appear to be connected distantly with the Bushmen of South Africa. These pygmies were, in all probability, well known to the ancient Egyptians. Traders and slave traders who journeyed up the Nile from Egypt in ancient days, and who brought back curious beasts from the black man's country, also returned with specimens of these little dwarfs. The pygmies also are written about by Herodotus, as everybody knows. The "cranes" with whom they fought were probably the ostriches of the Sudan. Persistent stories have been circulated from time to time of the existence of pygmy races or pygmy types in the forests of the Atlas Mountains in northwest Africa. Still more remarkable, fossil remains in Sicily, Sardinia, and the Pyrenees would seem to indicate the existence in Mediterranean Europe at one time of a negrito type, and a rude statuette found in the Pyrenees, and attributed to the Stone Age, would seem to show that these pygmies lingered on long after the invasion of the country by superior races. * * *

The little pygmies of the Congo forest do not themselves cultivate or till the soil, but live mainly on the flesh of beasts, birds, and reptiles, on white ants, bee grubs, and larvæ of certain burrowing beetles. Nevertheless they are fond of bananas, and to satisfy their hankering for this sweet fruit they will come at night and rob the plantations of their big, black agricultural neighbors. If the robbery is taken in good part, or if gifts in the shape of ripe bananas are laid out in a likely spot for the pygmy visitor who comes silently in the darkness

or dawn, the little man will show himself grateful and will leave behind him some night a return present of meat, or he will be found to have cleared the plantation of weeds, to have set traps, to have driven off apes, baboons, or elephants while his friends and hosts were sleeping. Children, however, might be lured away from time to time to follow the dwarfs, and even mingle with their tribe, like the children or men and women carried off by the fairies. On the other hand, it is sometimes related that when the negro mother awoke in the morning her bonny, big, black child had disappeared and its place had been taken by a frail, yellow, wrinkled pygmy infant, the changeling of our stories. Anyone who has seen as much of central Africa as I have and has noted their merry, impish ways, their little songs, their little dances, their mischievous pranks, unseen, spiteful vengeance, quick gratitude, and prompt return for kindness can not but be struck by their singular resemblance in character to the elves and gnomes and sprites of our nursery stories. At the same time we must be on our guard against reckless theorizing, and it may be too much to assume that the negro species ever inhabited Europe in spite of the resemblance between the stone implements of paleolithic man and those of the modern Tasmanians, and the Tasmanians were negroid if not negro. Paleolithic man in Europe may have been more like the Veddah, the Australian, the Dravidian, the Ainu than the Bushman or Congo pygmy. Undoubtedly (to my thinking) most "fairy" myths arose from the contemplation of the mysterious habits of dwarf troglodyte races lingering on still in the crannies, caverns, forests, and mountains of Europe after the invasion of neolithic man. But we must not too widely assume that these extinct pygmy races were negroes. They might well have been the dwarfed descendants of earlier and less definite human species; they may have been primitive Mongols or Eskimos. All the three species, or subspecies, of *Homo* have developed separately, repeatedly, and concurrently dwarf and giant races. Tall peoples have arisen independently one after the other in Patagonia, in equatorial Africa, in north Africa, Syria, northern Europe, and Polynesia. Stunted races have been evolved in several parts of Africa, in Scandinavia, Japan, the Andaman and Philippine archipelagoes, or among the Eskimos.

I am not inclined now to advocate the theory that the Congo pygmies of equatorial Africa are necessarily connected in origin with the South African Bushman. Some Bushmen tribes in southwest Africa, where better food conditions prevail, are scarcely dwarfs. The Bushmen and Hottentots are obviously closely interrelated in physical structure, but I can see no physical features (other than dwarfishness) which are obviously peculiar to both Bushmen and Congo pygmies. On the contrary, in the large and often protuburent eyes, the broad, flat nose with its exaggerated aloe, the long upper lip and but slight

degree of eversion of the inner mucous surface of the lips, the abundant hair on head and body, relative absence of wrinkles, of steatopygy, and of high, protruding cheek bones, the Congo dwarf differs markedly from the Hottentot-Bushman type. It is true that some of the Congo pygmies intercalate their speech with faucal gasps in place of guttural consonants, but this defect in pronunciation need not necessarily contain any reminiscence of the Bushman clock. There is one language spoken in eastern equatorial Africa (in the German sphere) which has the clicks—the Sandawi. But this, though it may be a relic of extremely ancient days, when the ancestors of the Hottentots were dwelling in east Africa, is not at the present time spoken by a people offering marked physical resemblances to the Congo pygmy or to the south African Hottentot.

In short, it would seem to the present writer that there is at present no evidence of any more relationship between the forest pygmies of equatorial Africa and the desert pygmies of southwestern Africa than the fact that both are early branches of the negro stem which probably diverged simultaneously at a remote period from the Ethiopian stock—sharing a few similar features in common—the one to hide in the forests between the Sahara and the Zambezi watershed, and the other to range over the prairies, steppes, and deserts of eastern and southern Africa. Perhaps the forest pygmies of to-day are more nearly allied to the west African Bantu and Nile negroes than they are to the Bushman-Hottentot group, which last is a section of the negro subspecies somewhat clearly marked off and separated from other negro races.

Many centuries ago these stunted little negroes—of yellowish skin and somewhat hairy bodies, of large heads, and of noses not only flat but with the wings much developed, and rising as high as the central cartilage of the nose—must have been the principal inhabitants of the Uganda Protectorate, sharing these wide and varied territories of forest, swamp, steppe, and park land with the prognathous type above described. At the present day, however, the number of actual typical pygmies existing in the Uganda Protectorate is very small, and their range is probably confined to a belt of forest lying to the east and west of the Semliki River, and perhaps to the dense woods on the southeast shores of the Albert Edward Lake. They are much more abundant in the Congo Free State, in whose forests they exist in a more or less undilated type southward to the verge of Angola, and north and northwest to the vicinity of the Barh-al-Ghazal and the German Cameroons. This pygmy type is also found within the territory of the German Cameroons, and in the interior of French Congo and Gaboon. It may even be found still to exist in the very remote parts of British Nigeria.

Dwarf negro races, possibly related to the Congo pygmies, are found in the vicinity of Lake Stephanie, in northeastern Africa, while the

dwarf type makes its appearance here and there in the eastern part of the Kingdom of Uganda (in the forests of Kiagwe), in the nomad of the Andorobo (a people of hunters which, in half-servile connection with the Masai, wanders over the greater part of eastern Africa between the Victoria Nyanza and the vicinity of the Indian Ocean), and amongst the people on the west and north of Mount Elgon.[a] No doubt, as Africa becomes more closely examined, the Pygmy type may be found to crop up elsewhere, either living as a separate people or reappearing as a reversionary type in tribes of more typical negro appearance, who in times past have absorbed antecedent dwarf races. * * *

AN HISTORICAL EXPLANATION OF THE GNOMES AND DWARFS OF FOLK-LORE.

Other dwarf races of humanity, belonging to the white or the Mongolian species, may have inhabited northern Europe in ancient times, or it is just possible that this type of pygmy negro which survives to-day in the recesses of inner Africa may even have overspread Europe in remote times. If it did, then the conclusion is irresistible that it gave rise to most of the myths and beliefs connected with gnomes, kobolds, and fairies. The demeanor and actions of the little Congo dwarfs at the present day remind one over and over again of the traits attributed to the brownies and goblins of our fairy stories. Their remarkable power of becoming invisible by adroit hiding in herbage and behind rocks, their probable habits in sterile or open countries of making their homes in holes and caverns, their mischievousness and their prankish good nature, all seem to suggest that it was some race like this which inspired most of the stories of Teuton and Celt regarding a dwarfish people of quasi-supernatural attributes. The dwarfs of the Congo forest can be good or bad neighbors to the big black people according to the treatment they receive. If their elfish depredations on the banana groves or their occasional thefts of tobacco or maize are condoned, or even if they are conciliated by small gifts of such food left exposed where it can be easily taken, they will in return leave behind them in their nightly visitations gifts of meats and products of the chase, such as skins or ivory. I have been informed by some of the forest negroes that the dwarfs will occasionally steal their children, and put in their places pygmy babies of ape-like appearance—changelings, in fact—bringing up the children they have stolen in the dwarf tribe. These collections of pygmies, which one can scarcely call tribes, certainly exhibit from time to time individuals of ordinary stature, and with features not strongly resembling those of the pygmy type.

[a] The resemblance of the dwarf types in West Elgon to the Congo pygmies is unquestionable; but I am not sure that the dwarf element in the Doko of northeast Africa and the Andorobo is not of Bushman characteristics.

TWO TYPES OF DWARFS.

The Congo pygmies appear to be divisible into two types, according to my own observations and to those of preceding travelers—one with a reddish or yellowish-brown skin and a tendency to red in the head hair, and the other a black-skinned type with entirely black head hair. It is possible that the original type of dwarf had a dirty brown skin, and a tendency to red both in the body and head hair, and that this type mingled anciently with the first true negro invaders of the forest—a people with decidedly black skins—and produced a black type of dwarf, which now seems to exist conjointly with the red or yellow pygmy; that is to say, in the same family of pygmies there may be both types. In stature, perhaps, the black type tends to be slightly taller than the other. The tallest specimen of pygmy measured by me or by my assistants was about 5 feet in height; but the average altitude for men was 4 feet 7 inches, and for women 4 feet 2 inches. Several of the men measured by me were only 4 feet 2 inches in height. One adult woman was just under 4 feet. There are two features which markedly distinguish these dwarfs from other negroes—the shape of the nose and the long upper lip. The nose has a very low bridge, and is exceedingly broad. The upper lip, besides being long and prognathous, is not so much everted as in the ordinary negro. The chin is very weak and receding. The neck is short, and the head is sunk rather between the shoulders, though not so markedly as in the ape-like types referred to in the first part of this article. The legs are short in proportion to the body, though they are usually sturdy little limbs. The feet are rather large, and much inclined to turn in, with the big toes pointing inward when they are brought together in a standing attitude. Hair on the face is present in many of the dwarfs. Some of the dwarfs have distinctly long beards, but I have myself seen only one with a beard of 6 inches in length. Belgians and Arabs who have traveled through the Congo forests have, however, assured me that they have met dwarfs at times who possessed beards of consider-



Measuring the height of a pygmy. The Englishman is 5 feet 11 inches; the pygmy, 4 feet 6 inches.

able length. The hair on the body is really of two kinds. There is, first, in many of the dwarfs - men and women - a survival in the adult of that hair which appears in the fetus in all human races, a soft brownish down. In addition to this survival of prehuman hair, the dwarfs possess, very often markedly, a development of hair that is peculiarly associated with the human species—namely, a fairly thick growth over the chest and stomach, in the armpits, and in the pubic region; also on the arms and legs. It is on the under parts of the body, curiously enough, that apes and monkeys tend to a decrease of hair. It is therefore somewhat curious that where body hair most frequently appears in the human race, it should be so often on the under side of the body, where (especially in the slightly stooping attitude which early man assumed) the hair is of less protection to the skin from the rain than if it grow on the back. In the pygmies this human body hair on the chest and stomach is black or blackish brown, and curly, like the hair of the head.

The dwarfs seldom wear anything in the way of ornament, and go about in their forests quite naked; but when in contact with negroes who wear a certain amount of clothing, the dwarfs will put on an apron of leaves or bark cloth sufficient to serve the purposes of decency. Their ears are not pierced. The only æsthetic adornment which they appear to adopt is the piercing of two holes in the upper lip. (This can be clearly seen in the head and bust of a dwarf woman.) Into the punctures they insert flowers, teeth, or porcupine quills.

HOW THEY LIVE IN THE FOREST.

The dwarfs are excessively shy in the forest, and are only visited with the greatest difficulty. They usually seem at the present day to attach themselves in their communities to the outskirts of the tribes of big negroes, with whom they usually enter into friendly relations. For a white man to see them in their homes it requires that one of these big negroes who is in friendly relations with the pygmies should go out into the forest and call to them loudly and repeatedly before a pygmy has sufficient confidence to show himself. Once their confidence is gained they will, no doubt, come in numbers. Even then it is extremely difficult to make inquiries of them concerning their life and customs.

The Congo pygmies keep no domestic animals, and do not practice agriculture. They live entirely by hunting, and eat the flesh of monkeys, of almost all other beasts, and birds, which they capture in their snares or shoot with their arrows, and they also feed on certain grubs, on honey, and on the bee grubs found in the honeycomb. They range the forests far and wide, indifferent whether they lose their way or not, since they sleep and feed in the forests and are in a sense always

at home. Seemingly they have only known the use of metal (iron) by their contact with negroes of superior race. Before this contact they seem to have used weapons and implements of wood, possibly also of stone. Even at the present day they not infrequently use wooden arrows.

Their huts are about 4 feet high and about 4 feet in diameter, and are usually built of withes or branches stuck into the ground at both ends, in a semicircle. Over this framework of bent boughs a thatch of large leaves is laid on, and a small hole is left at the side, through which the little pigmy crawls in to lie on his bed of leaves. The husband and wife (they seldom marry more than one wife) may share the same hut, but the children as soon as they have left the breast are put each into little huts by themselves. Some of these tiny habitations are absurdly small.

NO LANGUAGE OF THEIR OWN.

The dwarfs appear to have no language of their own, but simply to talk more or less imperfectly the tongue of the big negroes who are their nearest neighbors. Thus the dwarfs whom Stanley encountered on his various journeys across Congoland were always found to be speaking corrupt Bantu dialects, or in one instance a language scarcely differing from Manyema. Their pronunciation of these languages is imperfect, and they are much given to replacing certain consonants by little gasps, and sometimes by a sound which faintly recalls the South African click. They speak with a singularly musical intonation, their speech being almost intoned. Their pronunciation of words is rather staccato, each syllable being pronounced separately and distinctly. * * *

It is, of course, a hard thing to believe that prior to the invasion of the great west central African forest by the big black agricultural negroes the pygmy autochthones possessed no language but inarticulate cries and gestures.[a] Nevertheless, it would seem to be a fact that the pygmies, though so distinct a race, have no language peculiar to their race, but, wherever they are, speak (often imperfectly) the tongue of their nearest agricultural, settled, normal-sized neighbors. Again, it is strange that this little people should speak imperfectly these borrowed tongues, because individuals transported from the pigmy milieu have picked up rapidly and spoken correctly Sudanese Arabic, Runyoro, Luganda, Kiswahili, and Kinyamwezi. It is, however, less singular an anomaly than the contrast between the brutish lives led by the pygmies in their wild state—lives, perhaps, in absence of human culture nearer to the beast than is the case with any recently existing

[a] I was much struck, and so were my European companions, at the expressive gestures used by the pygmies in eking out their conversation. One often conversed with them in gestures.

race of men known to us—and the vivacious intelligence, mental adroitness, almost fairy-like deftness they exhibit when dwelling with Europeans. No one can fail to be struck with the mental superiority they exhibit under these novel circumstances over the big negro, whose own culture in his own home is distinctly higher than that of the forest pygmies. * * * They are very fond of singing and dancing, and the little songs that they croon are distinctly melodious, while spectators are kept in fits of laughter by their truly droll and elfish antics. When they give a musical performance they are fond of seating themselves in a semicircle. In their own homes, on these occasions, they beat drums, which are made of sections of hollow trees covered with skin. While thus seated, and beating drums, they chant songs, and dance, so to speak, all over their bodies, striking the ground with their elbows and hips, knees and hands, wagging their heads, and heaving their stomachs up and down. The dances which they perform upright are sometimes of a markedly indelicate kind, though the dwarfs seem only to be carrying out the ancient traditions.



The most primitive musical instrument. Mbuba negro playing on a string.

IMITATIVE AND ADAPTIVE.

The Congo dwarfs, though they may exhibit ape-like features in their bodies, and though in their natural life they are absolutely savage, display nevertheless a certain alertness which gives one the impression that they possess quicker intelligence and a greater adaptability of mind than the ordinary big negro. They are admirable mimics. They learn languages easily, though they may speak them with a defective pronunciation. The little dwarf women readily attach themselves to negroes of the big races, and make affectionate and dutiful wives. When Captain (now General Sir Frederic) Lugard journeyed through the Semliki forests, the Sudanese soldiers by whom he was accompanied brought away with them several dwarf women whom they married. It used to be an amusing sight to see husband and wife together, the husband perhaps 6 feet in stature and broad in proportion, and the little wife 4 feet only, and disproportionately broad.

AN IMPORTATION OF DWARFS INTO THIS COUNTRY.

American readers may be interested to learn that it is possible there still exist at the present day traces of African dwarf races in the negro population of the West Indies. This, at any rate, was the case forty or fifty years ago. There is a tradition to the effect that among the slaves shipped from the Congo regions at the end of the eighteenth century were specimens of dwarf races from the far interior. In Trinidad and some of the southern islands of the West Indies these little people remained for a time distinct from the other slaves, and people of my acquaintance still living have seen and spoken to them. They were recognized at the time as being quite distinct from the ordinary negro type, and were generally known as the "Congo dwarfs."

GUAM AND ITS PEOPLE.[a]

By W. E. Safford.

The Marianne Islands, or Ladrones, form a chain about 420 miles long in a north and south direction and lying about four days' run by steamer to the eastward of the Philippines. More definitely speaking, they extend from 13° 14′ to 20° 30′ north latitude and lie between 142° 31′ and 143° 46′ east longitude. They are of volcanic origin and are surrounded by coral reefs. In the northern islands there are a number of volcanoes in full activity, but in the south volcanic action had ceased long before their discovery.

Guam, the largest and most important member of the group, is the only island belonging to the United States, the remainder having been sold by Spain to Germany after the close of the late war. It is at the extreme south of the chain and at present has a population of 9,676.[b] The island is of irregular shape and is about 29 miles long from north-northeast to south-southwest. At its narrowest part, near the middle, it is less than 4 miles across; near the ends the breadth is from 7 to 9 miles.

The northern portion of the island consists of a mesa, or plateau, an ancient coral reef, elevated about 150 feet above the sea level, with one or two peaks of no great height extending through it. It is without streams or springs, owing to the porous nature of the coral, except in the immediate vicinity of the peaks referred to, where in the wet season there is for a time a supply of water. Near the middle of the island, in the immediate vicinity of Agaña, the capital, there is a large spring from which a copious supply of water issues. This, after slowly oozing through an extensive swamp—an ancient lagoon—finds its way into the sea by means of a river, the channel of which has been artificially lengthened and turned for a mile parallel to the coast for the convenience of the natives. The southern portion of the island is principally of volcanic formation, with several peaks which scarcely exceed a thousand feet in height. It contains a number of streams,

[a] Reprinted by permission, after revision by the author, from the American Anthropologist (N. S.), vol. 4, October-December, 1902. See also "The Chamorro language of Guam," by the same author, in American Anthropologist (N. S.), vol. 5, pp. 289 ff.

[b] This number refers to the actual residents of the island and does not include visitors nor the United States forces stationed there. The figures are taken from the census of 1901, and were kindly communicated to me by Don Pedro Duarte, late captain in the Spanish army, now a resident of the island.

some of which lose themselves beneath the surface for a time and reappear issuing from caverns. As in most calcareous formations, funnel-shaped sink holes are of frequent occurrence, the water draining into them sometimes reappearing near the beach in the form of springs, or spurting forth in places from beneath the sea.

Soil.—Near the junction of the volcanic and coral formations the limestone presents a crystalline structure, pure crystals of carbonate of lime being frequently found; and nodules of flint similar to those from European chalk formations are met in certain localities. The soil of the greater part of the island is thin and red. It owes its color to the oxide of iron present in the disintegrated coral of which it is principally composed. In the valleys and forests there is an accumulation of vegetable mold, and in swampy places the soil is black, rich, and suitable for the cultivation of rice.

Climate.—Guam is situated on the dividing line between the northeast trade winds and the area of the monsoons of the China Sea. From December to June the prevailing winds are from the northeast, the temperature is agreeable, the nights cool, and the air is refreshed by occasional showers. The most agreeable months are March, April, May, and June. During July and August southwest winds are frequent and are accompanied by heavy rain squalls. Hurricanes may occur at almost any time of the year. They may be expected at the changes of the monsoons and are most frequent in the months of October and November. They are often of such violence as to blow down the greater part of the native houses, laying waste the maize and rice fields, uprooting or breaking off cocoanut trees, destroying the breadfruit crop, tearing to shreds plantains and banana plants, and killing fowl and cattle. Vessels at anchor in the harbor are frequently swept from their moorings and cast upon the reef, as the letter books of the Spanish governors of the island will show. Hurricanes are usually followed by scarcity of food. The natives, who very seldom have a reserve on hand, are obliged at such times to go to the forest for wild yams and cycas nuts.

Earthquakes are also frequent, but are not often violent. One of the most severe the island has known in historical times was that of 1849, which destroyed the church and the government house in the village of Umata. Not long afterwards a number of natives of the Caroline Islands appeared at Guam, stating that their islands had been swept by enormous waves, and begging the governor for an asylum. The most recent occurred September 22, 1902, causing serious injury to the building used as the marine barracks, and killing several natives.

Vegetation.—The flora of Guam, though possessing a number of species not known from other localities bears a general resemblance to that of many other volcanic, coral-fringed islands of the Pacific. In the



GUAM. PUNTA PITI, THE LANDING PLACE, HARBOR OF SAN LUIS DE APRA.



FIG. 1.—THE VILLAGE OF ASAN, GUAM, SHOWING TYPICAL HOUSES, AND COW HARNESSED TO VEHICLE.



FIG. 2.—LANDING PLACE AT PITI; COCOANUT TREES NOTCHED FOR GATHERING TUBA.

forests are wild breadfruit trees of great size;[a] giant banyans and other species of the fig family; tall trees, with hard, mahogany-like wood; arboreous Apocynaceæ, several species of screw pines; and a wealth of ferns growing on the ground, climbing tree trunks, or perched upon the branches like great birds' nests. In rocky places grow the ramie-fiber[b] plant, in its wild state as a branching shrub or small tree, and a cycad, resembling a tree fern, with glossy, plume-like fronds.[c] In the savannas, or places devoid of forest growth, occur vast stretches of a coarse grass called neti, patches of a brake-like fern,[d] and scattered ironwood trees.[e] The ironwood grows also along the sandy beaches, especially on the east coast of the island, where the trees present a twisted and battered appearance, from the constant trade winds and the effects of the frequent hurricanes. In the rich valleys the betel-palm is plentiful;[f] and near the banks of streams grow a tree fern (Alsophila) and giant arums.[g] Twining in the thickets are several species of morning-glories, plants of the bean family, wild yams, with sharp, wiry branching thorns, and a peculiar leafless, wiry parasite.[h] In the swamps are dense growth of reeds and marsh ferns. The vegetation along the beach is like that of most tropical shores, made up of goats-foot convolvulus, sea beans, and shrubby plants with fleshy and hairy leaves. On the rocky islets, besides the Cycas mentioned above, grows a fine hard-wood tree called chopag by the natives.[i] In the swamps are tangled growths of mangroves propped up on aërial roots and crimson-flowered Lumnitzeras.

It may be of interest to those unfamiliar with Pacific insular floras to note the absence of pines, cedars, willows, walnuts, birches, cacti, and plants belonging to the rose family; there are few composites and but one or two crucifers. It is probable that none of the palms are indigenous, with perhaps the exception of a wild rattan (Calamus) of no economic value.

Fauna.—Besides rats and mice the only mammals are a large fruit-eating bat, or flying fox;[j] a small insectivorous bat which during the daytime remains in caves; wild hogs, and a species of deer introduced into the island by Don Mariano Tobias, who was governor from 1771 to 1774. The deer are now so abundant as to cause serious damage to the corn crops and young cocoanuts. Goats are also to be found on several of the outlying islets. Cattle and carabaos, or water buffalo, have been introduced and are used both for food and as beasts of burden.

Among the birds are several species of fruit doves, a pretty little fan-tailed flycatcher, scarlet-and-black honey eaters with long, slender

[a] *Artocarpus communis.*
[b] *Bœhmeria nivea*, var. *tenacissima.*
[c] *Cycas circinalis.*
[d] *Gleichenia dichotoma.*
[e] *Casuarina equisetifolia.*
[f] *Areca catechu.*
[g] *Alocasia spp.*
[h] *Cassytha filiformis.*
[i] A species of Ochrocarpus.
[j] *Pteropus keraudreni.*

curved beaks, black starlings, a crow, a tawny-and-blue kingfisher (Halcyon), which preys on lizards and insects instead of fish, the swift that makes edible nests, a little flycatcher named for De Freycinet, a small Zosterops with olive-green and yellow plumage, two rails (Hypotænidia and Poliolimnas), and a gallinule, which frequent the swamps and taro patches; and along the shores a heron, a bittern, two curlews, the Pacific godwit, several sandpipers, plover, the wandering tattler, sanderling, snipe, and turnstones. The only bird of prey known to occur is the widely spread short-eared owl,[a] called momo by the natives. The most beautiful of the birds are the fruit doves, one of which[b] belongs to a group widely spread in the Pacific, having rosy crowns, green backs, and yellow, purple, and orange plumage on the under surface. The only song bird is the reed warbler,[c] a modest bird bearing a general resemblance to our catbird and having an exquisite song.

Among introduced species are the beautiful little Chinese partridge,[d] brought to the island in recent years by Don Pedro Duarte, and the Philippine turtledove. There is also a fruit-eating dove, interesting from the great dissimilarity between the adult male and the female.[e] The former, called "apaka" by the natives, is considerably the larger and has a white head. The latter, called "paloman kunau," is of an almost uniform chocolate color. The natives think them to be different birds which live together.

The best game bird is a wild duck, *Anas oustaleti*, a species peculiar to the island, but closely allied to *Anas superciliaris*, which occurs in Samoa. Curlew, gallinules, plover, and doves are also hunted by the natives for food.[f]

Among the reptiles are a large lizard (Varannus) which robs bird's-nests and eats young chickens and pigeons, a blue-tailed skink, one or two geckos which frequent the houses of the natives and run about the ceilings and walls catching insects, and a small snake (Typhlops), very much in general appearance like an earth worm, but with a hard, glossy skin composed of minute scales.

Several species of land crabs occur, including the curious *Birgus latro*, or "robber crab," kept by the natives in captivity and fattened on cocoanuts for the table. In the streams there are shrimps and on the shores spiny lobsters; both of these are highly esteemed for food. A full list of the fishes and birds is given in the report of the director

[a] *Asio accipitrinus.*
[b] *Ptilinopus roseicapillus.*
[c] *Acrocephalus luscinia.*
[d] *Excalfactoria sinensis.*
[e] *Phlegœnas xanthonura.*
[f] See "Birds of the Marianne Islands and their vernacular names," by W. E. Safford, The Osprey, March–April, 1902.



FIG. 1.—ON THE ROAD TO AGAÑA.



FIG. 2.—A WAYSIDE CHAPEL.



VIEW NEAR PITI, GUAM, SHOWING FRAMEWORK OF HUT LASHED TOGETHER WITH PANDANUS LEAVES.

of the Bernice Pauahi Bishop Museum of Hawaii for 1900, the result of the work of Mr. Alvin Seale, who collected on the island in 1900.

Discovery.—The island of Guam was discovered by Magellan on March 6, 1521, after a passage of three months and twenty days from the strait which bears his name. Among the accounts written of his expedition, that of Antonio Pigafetta, of Vicenza, who accompanied him, is full of valuable and interesting details. Pigafetta tells of the terrible suffering of his companions on their way across the waters of the unexplored ocean; how their food failed, until they had only crumbling biscuit full of maggots to eat, all foul from the excrement of rats; how they were forced to eat the rats themselves, which brought a price of half a crown each, and, moreover, "enough of them could not be got;" how they even resorted to sawdust of wood, and the ox-hides used as chafing gear in the rigging under the main yard, all stiffened and hardened by sun, rain, and wind, soaking them for several days in the sea, and then putting them "a little on the embers." The water they had to drink was yellow and stinking, and the gums of nearly all were swollen with scurvy, and nineteen died, and twenty-five or thirty others fell ill "of divers sicknesses, both in the arms and legs and other places, in such manner that very few remained healthy."

Two islands were sighted, but only birds and trees were found upon them and no supplies could be obtained. These they called the Unfortunate Islands. Finally three other islands were sighted, covered with rich vegetation and inhabited by many people, who came out to meet them in wonderful canoes, which seem to fairly fly over the water. The sails were triangular-shaped mats woven of pandanus leaves and were supported on a yard after the manner of lateen sails. The mast was amidships. Instead of going about in tacking they simply shifted the sheet of the sail from one end of the canoe to the other, so that which had been the bow became the stern, and the stern became the bow. Parallel to the fore-and-aft line there was an outrigger or log, rigidly connected with the hull by cross pieces and resting upon the surface of the water. This served, both by its weight and buoyancy, to keep the narrow craft from capsizing, and was kept always on the windward side by shifting the sheet as described above. All of the boats were painted, some black and others red. They had paddles of the form of hearth shovels, which could be used for steering or propelling the boats.[a]

The ships came to anchor near a village on the southernmost island, and the natives brought them refreshment of fruits. The sails were

[a] "Hanno il timone simile ad una pala da fornaio, cioè una pertica con una tavola in cima; e doppio essendo questo timone o remo, fanno a piacer loro di poppa prora."—Pigafetta, Primo Viaggio intorno al Globo Terracqueo, Milano, MDCCC, p. 53.

furled and preparations were made to land, when it was discovered that the skiff which rode astern of the flagship was missing. Suspecting that the natives had stolen it, the captain-general went ashore with 40 armed men, burned forty or fifty houses and many boats, and killed seven or eight native men and women. He then returned to the ship with his skiff and immediately set sail, continuing his course to the westward.

"Before we went ashore [says Pigafetta] some of our people who were sick said to us that if we should kill any of them, whether man or woman, that we should bring on board their entrails, being persuaded that with the latter they would be cured.

"When we wounded some of those islanders with arrows, which entered their bodies, they tried to draw forth the arrow now in one way and now in another, in the meantime regarding it with great astonishment, and thus did they who were wounded in the breast, and they died of it, which did not fail to cause us compassion.

"Seeing us taking our departure then, they followed us with more than a hundred boats for more than a league. They approached our ships, showing us fish and pretending to wish to give them to us; but when they were near they cast stones at us and fled. We passed under full sail among their boats, which with greatest dexterity escaped us. We saw among them some women who were weeping and tearing their hair, surely for their husbands killed by us."

Aboriginal inhabitants.—The natives were described by the early navigators and missionaries as people of the stature of Europeans. They were lighter in color than the Filipinos, and the women and children were fairer than the men. At the time of the discovery the men wore their hair loose or coiled in a knot on top of the head. Later they are described as shaving the head, with the exception of a crest about a finger long, which they left on the crown. Some of them were bearded. Pigafetta says that they were well formed, and in the report of the early missionaries they were said to be more corpulent and robust than Europeans, but with a tendency to obesity. They were remarkably free from disease and physical defects, and lived to a great age. Among those baptized the first year by the missionaries there were more than 120 said to be past the age of 100 years. Their hair was naturally jet black, and in early times was worn so long by the women as to touch the ground. The men wore no clothing, and the only covering of the women was a small apron-like garment made of the inner bark of a tree. The women were handsome, and more delicate in figure than the men. They did not work in the fields, but occupied themselves in weaving baskets, mats, and hats of Pandanus leaves, and doing other necessary work about the house.[a]

[a] Le donne son belle, di figura svelta, piu delicate e bianche degli uomini, con capegli nerissimi sciolti e lunghi fino a terra. Vanno pur esse ignude, se non che coprono le parti vergognose con una corteccia stretta e sottile quanto la carta, tratta



FIG. 1.—ENTRANCE TO AGAÑA, THE CAPITAL OF GUAM.



FIG. 2.—THE BRIDGE BETWEEN PIGO AND ANIGUA.



AGAÑA. THE TRIBUNAL.

In their general appearance, language, and customs the people of Guam bore a resemblance to the Tagalos and Visayans of the Philippine Islands. The vocabulary, however, was distinct, with the exception of a few words of Malayan affinity widely spread over the Pacific (such, for instance, as the names of sky, fowl, fire, and a few others). Their grammatical forms were very different from those of the Polynesians, tenses being expressed by the reduplication of syllables and the insertion and prefixing of particles to the root of the verb.

Before marriage it was customary for young men to live in concubinage with girls, whom they purchased from their parents by presents. This did not injure a girl's prospects for marriage afterwards. Frequently a number of young men and young girls would live together in a large public house. After marriage a husband contented himself with one wife and a wife with one husband at a time. Divorces were frequent, the children and household property always going with the wife. The most frequent cause of divorce was jealousy. If a woman discovered her husband to be unfaithful, she called together the other women of her village, who armed themselves with spears and proceeded to the house of the offender. They would then destroy any growing crops he might own and menace him with the spears until he was forced to flee from the house. Then they took possession of everything they could find, and sometimes even destroyed the house itself. When a wife was unfaithful, the husband had a right to chastise her paramour, but she went free from punishment.

Caste distinctions were recognized and very strictly observed. The chiefs, called chamorris, owned vast plantations and cocoanut groves, which were handed down generation after generation to the heirs. A chief's rightful successor was his brother or his nephew, who, on coming into possession of the family estate, changed his name to that of the chief ancestor of the family.

The people were naturally superstitious. They venerated the bones of their ancestors, keeping the skulls in their houses in small baskets, and practicing certain incantations before them when it was desired to attain certain objects. The spirits of the dead were called aniti, and were supposed to dwell in the forests, often visiting the villages, causing bad dreams and having especial sway over the fisheries. People dying a violent death went to a place called Zazarraguan, or the house of Chayfi, where they suffered torture from fire and incessant blows. Those dying natural death went to a subterranean paradise where there were groves of cocoanuts, plantations of bananas, sugar cane, and other fruits in abundance. Certain men called makahna resembled the kahunas of the Hawaiians. They were sup-

dalla scorza interna che sta fra la corteccia il legno della palma. Esse non lavarono alla campagna, ma stanno in casa tessendo stuoie, ceste di palma, e altri simili lavori facendo necessarj alla famiglia.—Pigafetta, p. 51.

posed to have power over the health of the natives, could cause rain, and bring luck to the fishermen. As among many Indian, Malayan, and Polynesian peoples, they were very careful not to spit near the house of another, undoubtedly through fear of sorcery, should an enemy possess himself of the spittle.

Violent grief was shown on the death of a friend or relative, the people wailing and singing dirges expressive of their sorrow and despair, and recounting the noble qualities of the dead. In the case of a chamorri's death the wailing was prolonged for several days. Small mounds were raised over the grave and were decorated with flowers, palm leaves, canoe paddles if the deceased was a fisherman, and spears if he was a warrior. The body was sometimes anointed with fragrant oil and taken in procession from house to house, as though to allow the spirit an opportunity of choosing an abiding place among the homes of its kindred.

On occasions of festivity the men and women would collect in groups, each by themselves, and, forming semicircles, sing and chant their legends and fables. Sometimes these songs would be in three-part harmony, "treble, contralto, and falsetto." The songs were accompanied by appropriate gestures and movements of the body, the women using certain rattles and castanets made of shells. On these occasions the women adorned their foreheads with wreaths of flowers like jasmines, and wore belts of shells and bands from which hung disks of turtle shell, which was much prized among them. They wore skirts of fringe-like roots, which the early missionaries declared were "rather like cages than garments."

Though called Ladrones (thieves), they were so honest that their houses were left open and without protection, and very seldom was anything found missing. They were very hospitable and kind, as all the early accounts testify. It was not until they were given just cause that their attitude toward the Spanish changed, whereupon the latter declared that they had been mistaken in attributing virtues to them.

They declared that the foreigners brought to the islands rats, flies, mosquitoes, and strange diseases. They lived with little restraint, matters of importance to the villages or to the general public being decided by assemblies of their chiefs and old men; but these had little authority, and a native did pretty much what he pleased unless prevented from doing so by some one stronger than himself.

Their arms were wooden spears pointed with bones, and slings with which they threw oval-shaped stones with remarkable force and accuracy, "as far," says one observer, "as an arquebus can shoot." From their earliest youth they were accustomed to practice with these weapons, and often had contests of spear throwing, fencing, and throwing at marks. Often the stone was hurled with such swiftness that it would become embedded in the trunk of a tree. The women went to sea with their husbands for sport. They were fine swimmers, and as





NATIVES OF GUAM.



OLD CHURCH AND BELFRY AT AGAÑA.

they threw themselves into the water and came bounding from wave to wave they reminded Pigafetta of dolphins.

Their houses were well made, thatched with palm leaves, and raised on wooden posts or on pillars of stone.[a] They were divided into several rooms by partitions of mats. Their beds were mats woven from Pandanus leaves divided into strips of great fineness. Their boats were kept under shelter, large sheds being constructed for them near the sea, the stone or masonry pillars of which may still be seen. These stone pillars are held in awe by the present natives of the island, who think it unlucky to disturb them or even to linger near them.

Fire.—It was asserted by the early missionaries that the aboriginal inhabitants were ignorant of fire before the advent of the Spaniards. That this is a mistake is shown not only by the fact that their principal food staples could not be eaten without cooking, but also by their words pertaining to fire and cooking, as *guafi* (fire), *apo* (ashes), *aso* (smoke), *tuno* (roast), *mañila* (flame), *pinigan* (live coal), *soñgge* (burn, v. t.), *hanon* (burn v. in.), *sotne* (boil), *peha* (cook in embers), *chahan* (bake in ancient oven), and other words. Many of these words are to be found with slight modifications in other languages of Malayan, Melanesian, and Polynesian affinities.

Food.—The food of the aborigines consisted of fish, fowls, rice, bread fruit, taro, yams, and bananas (Pigafetta calls them "figs a palm long"), cocoanuts, and nuts of *Cycas circinalis*, the poisonous properties of which they removed by soaking and repeatedly changing the water, after which they were cooked. For relishes they ate certain seaweeds, the nuts of the wild "almond,"[b] and a species of screw pine.[c] Pandanus drupes, which are an important food staple in some Pacific islands, were not a part of their domestic economy; and, although they had pigs at an early date, it is probable that these were introduced after the discovery, as some of the early navigators declare that the natives could not be induced to eat flesh. The creamy juice expressed from the meat of ripe cocoanuts entered into the composition of several of their dishes. They were ignorant of the manufacture of fermented tuba from the sap of the cocoanut, and had no intoxicating beverages before the arrival of the Spaniards. As was nearly the universal custom throughout the tropical Pacific, they cooked by means of stones which they heated in a hole in the ground, making alternate layers of food, leaves, and heated stones, somewhat after the manner of a New England clambake.

Narcotics.—The kava pepper (*Piper methysticum*) was unknown to them; but its place may be said to have been taken by the betel pepper, the leaves of which they chewed wrapped around a fragment of the

[a] "Fundados sobre fuertes pilares de piedra."—Narrative of Gaspar and Grijalva, who visited Guam with Legaspi in 1565.

[b] *Terminalia catappa.*

[c] Pandanus sp.

nut of the betel palm, with the addition of a pinch of lime. This habit is still universal among the natives of Guam. The betel thus prepared has an agreeable aromatic pungency, not unlike that of nutmeg. It imparts a fragrance to the breath, which is not disagreeable, but it discolors the teeth in time and causes them to crumble away, while the constant expectoration of saliva, red like blood, is a disagreeable habit.

Cultivated plants.—The principal plants cultivated by the natives before the discovery were the bread fruit—a sterile form of *Artocarpus communis*, which is propagated by cuttings, or sprouts, from the roots; the *dugdug*, or fertile form of the same species, which also grew wild upon the island, yielding an edible, chestnut-like seed, logs from which they made their largest canoes, bark for their aprons or loin cloths, and gum which served as a medium for mixing their paints and as a resin for paying the seams of their canoes; the betel palm (*Areca catechu*) and the betel pepper (*Piper betle*), which were undoubtedly brought to the island in prehistoric times, as also were rice, sugar cane, and the species of Pandanus called aggak, from the leaves of which they made their mats, baskets, hats, and boat sails. Of this plant only one sex occurs on the island, and it must consequently be propagated by cuttings. Cocoanuts were also, in all probability, brought hither, as were several varieties of yams,[a] separated by them into two groups, which, according to the shape of the leaf, they call nika and dago. A third species,[b] called gado, which now grows wild in thickets, is characterized by sharp, wiry, branching thorns near the ground, which serve to protect its starchy tubers from wild hogs. Several varieties of taro were cultivated, both in swampy places and on dry hillsides. Among the less important plants were the Polynesian arrowroot, called gabgab;[c] turmeric (*Curcuma longa*), called mango; wild ginger or asñgod halom-tano; and a species of red pepper, called doni. There were no edible oranges, mangoes, mangosteens, nor loquats. A fruit much relished by the fruit-eating pigeons was the piod (*Ximenia americana*), which resembles a small yellow plum with a slight flavor of bitter almond.

Agricultural and other useful arts.—For growing taro little art is required. Yams require more care; while bananas, breadfruit, and the textile pandanus, propagated by cuttings or sprouts, have to be severed from the parent stock, stuck into the ground, and occasionally watered. For the cultivation of rice—the only cereal of the aborigines—far greater skill is required on account of the necessary preparation of the fields and the construction of irrigating ditches. Rice was the principal staple furnished to vessels in considerable quantity. Oliver van Noort, who visited the island in 1600, mentions it in his narrative, and the Nassau fleet in 1625 bought it in bales containing

[a] *Dioscorea alata* and *D. aculeata*. [b] *Dioscorea spinosa*. [c] *Tacca pinnatifida*.

70 to 80 pounds each. At this time it was cultivated in many places on the island, which indicates no little industry and enterprise on the part of the natives. I dwell on this point because the aborigines of Guam have been described as very indolent and of the lowest order of civilization, ignorant even of the art of making fire. Surely the people who constructed such marvelous "flying praos," who dwelt in commodious and well-built houses, and who carried on the art of agriculture to the extent indicated by the narratives of the early expeditions of the Dutch, can not be classified as abject savages, even though their bodies were covered by very scant clothing. If encounters took place between them and the crews of visiting ships—and these crews, fresh from pillaging the coast of South America and accustomed to deeds of violence and murder, were in all probability far from gentle in their treatment of the natives—they were designated as miserable infidels, to "slay" whom was a legitimate pastime; while, if a European was killed by one of them, without investigating the cause, he was declared to have been murdered, and his death was avenged by the burning of villages, boats, and boathouses, and by killing men, women, and children.[a] They were branded with the name "Ladrones" for stealing a boat and some bits of iron; yet the Spaniards did not hesitate to steal human beings to serve as slaves at their pumps.[b]

Arrival of Jesuit missionaries.—For nearly a century and a half after the discovery no attempt was made to colonize the island. Spanish galleons on their annual trips from New Spain to the Philippines stopped regularly at Guam for fresh water and provisions. On one of these a Jesuit priest, Padre Diego Luis de Sanvitores, was passenger. His heart was moved with pity for the natives living in spiritual darkness in this earthly paradise, and when he reached Manila he begged that he might be sent to them as a missionary. His request was refused, and it was not until he succeeded in getting a direct order from the King, Philip IV, that his wish was realized. A ship was built at Cavite, and Padre Diego was sent, together with several companions, to carry the faith to the Ladrones.

He arrived at Agaña on March 3, 1668, the ship having first proceeded to Acapulco, Mexico, as was the custom, owing to the easterly winds and the currents which prevail in the latitude of Guam. Sanvitores was full of zeal and worked with phenomenal success among the natives. They received him with great kindness, giving him a dwelling place and building for him a church at Agaña. Letters written by him to his superiors are full of interesting information concerning the natives. He tells of their great regard for caste distinctions, their veneration for the bones of their dead, their

[a] See narrative of the expedition under Miguel Lopez Legaspi, which visited Guam in 1565.

[b] Burney, Narrative of the Loaysa Expedition, 1526, vol. 1, p. 217.

practice of sorcery, and he regrets their love of worldly pleasures, their disinclination for serious occupations, and complains that their history is "obscured by a thousand fables."

After a time trouble arose between the missionaries and the natives. At first the chiefs insisted that the benefits of baptism should not be extended to the common people; then they began to doubt its efficiency, and many who had been baptized reverted to their former beliefs and practices. They resented the efforts of the missionaries to change their marriage customs, the destruction of the sacred bones of their fathers, and the forcible detention of children whom the missionaries had taken to educate. Finally, after four years of unceasing labor among them, Padre Sanvitores was killed while baptizing a child against the will of its father.

Active measures were now taken to reduce the natives. The Queen of Spain, Maria Ana of Austria, widow of Philip IV, became interested in their conversion and founded a college for the education of native youth, which she endowed with an annual income of 3,000 pesos. In honor of her the group was named "Las Islas Marianas." The income from the fund bestowed by the Queen continued until the seizure of the island of Guam by the United States.

The Jesuits continued in the island for a century. At their expulsion, in 1769, in conformity with the edict of Carlos III, their place was taken by Recollet friars of the order of San Agostino. During their stay the Jesuits not only introduced many useful plants and fruits from Mexico and from other countries, but they taught the natives many useful arts and habits of industry, established extensive plantations, and brought to the island cattle, horses, mules, donkeys, goats, and carabaos, or water buffalo. The youths under their care were instructed in the elements of learning and in the Christian doctrine, and were trained to serve as acolytes. They instructed them also in music. The inventory of their effects, taken at the time their property was seized by order of the King, is still in Guam. Among the items are "seven violins with their bows, three sweet flutes, two harps, and one viol." The inventory also includes a list of blacksmith's tools, axes, planes, chisels, saws, and appliances for tanning leather, together with a good supply of agricultural implements, and the list of live stock and articles found on their farms showed that the latter were in a flourishing condition.

Plants introduced by the missionaries.—The principal plants introduced by the missionaries were maize, or indian corn, tobacco, oranges, lemons, limes, pineapples, cashew nuts, or marañones, peanuts, egg plants, tomatoes, and several species of Anona, besides a number of leguminous vegetables and garden herbs.

With maize, the chief article of cultivation, came the Mexican metatl and mano for making tortillas. Tobacco leaves were used for

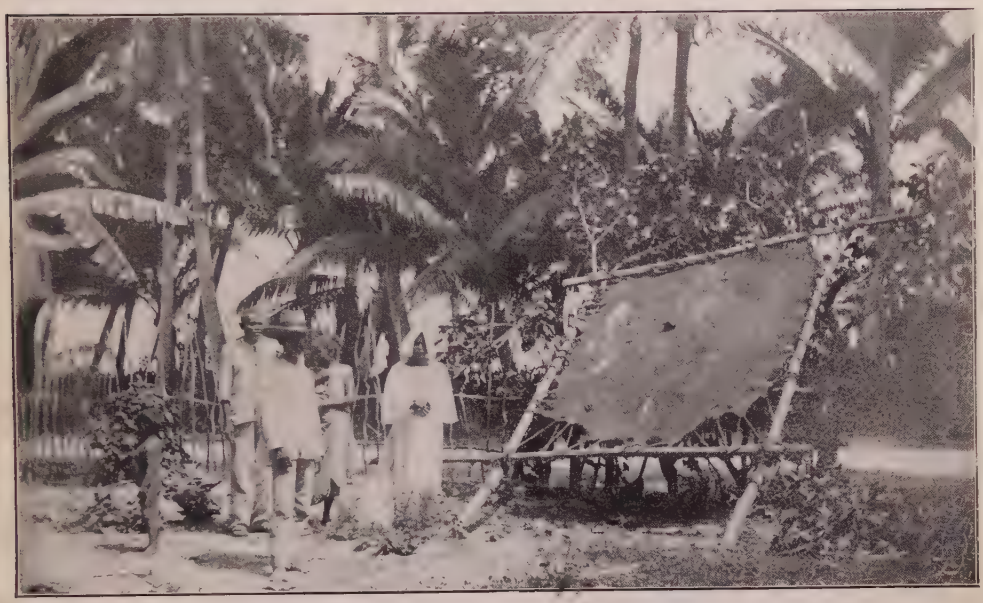


FIG. 1.—TANNING AN OXHIDE IN GUAM.



FIG. 2.—DRYING MAIZE IN THE STREETS OF AGAÑA, GUAM.



FIG. 1.—OVEN FOR BAKING BREAD AND BREADFRUIT, A MEXICAN INTRUSION.



FIG. 2.—HULLING RICE IN WOODEN MORTAR.

paying the natives for their work. Most of the sweet potatoes grown were sold to ships, the natives contenting themselves with yams and taro, or breadfruit. Among the medicinal plants brought from Mexico was *Cassia alata*, which is still called "acapulco;" and *Pithecolobium dulce*, called "kamachilis," was brought for the sake of its bark, which is used in tanning. Coffee and cacao were introduced later.

Modern agriculture.—Maize is cultivated in patches varying from 1 to 10 acres. It is planted on the highlands at the beginning of the rainy season. A second crop is obtained from the lowlands in the dry season. It must be shelled as soon as gathered, carefully dried to prevent molding, and stored in large earthen jars (brought from Manila, Japan, or China) for protection against weevils. In the lowlands, with deep soil, the fields may be plowed. In plowing, bullocks or carabaos are used, the latter preferably in wet places; the plow is of wood, with a single handle, and tipped with iron, usually forged by the village blacksmith from an old musket barrel.

Coffee produces most prolifically, and in sheltered valleys where the soil is deep and rich cacao of excellent quality is grown.

Rice is cultivated very much as in the Philippines. The crop is frequently a failure, owing to drought of a blasting hurricane; and even in good seasons the crop is insufficient for the consumption of the inhabitants. It is one of the food staples of the island, and is now imported from Japan and the United States.

Taro is cultivated both in wet and in dry ground. It is much eaten by the natives, as also are several species of yams. There are at least four varieties of sweet potatoes. It is interesting to note that the vernacular name for sweet potatoe—camote—is of American origin, and is still commonly used among the Spanish-speaking people of our extreme Southwest.

Tobacco is planted by nearly every family. It must be carefully weeded and kept free from insect larvæ, the most destructive of which is that of a sphinx moth. It is never cured nor allowed to ferment, but is simply hung under shelter and left to dry. The natives prefer their tobacco to all other kinds. They will not smoke foreign tobacco unless their own gives out. It is usually smoked in the form of loosely rolled cigars, made without paste, and wrapped with agave or pineapple fiber.

Several kinds of Leguminosæ are cultivated both for the sake of their green pods and for their ripe seeds. One of the best is *Psophocarpus tetragonolobus*, the pods of which, eaten green and tender, have four longitudinal ruffle-like wings. Peanuts grow readily, in places lining the road from Agaña to the port. Mandioc and arrowroot (*Maranta arundinacea*) are cultivated, but not on an extensive scale; and tumeric and tacca, though growing wild, are sometimes planted.

The natives have become essentially an agricultural and pastoral

people. Some of the changes brought about by Spanish occupancy are shown in the accompanying illustrations. Navigation is scarcely practiced by them. The wonderful flying praos have been replaced by small canoes of inferior type, which are now used by the natives only for fishing. There are scarcely more than a dozen native boats in the whole island. For years what traffic was carried on between the islands of the group was by means of large canoes from the Caroline Islands.

Another figure shows the manner in which corn is spread out to dry in the streets upon mats of Pandanus leaves. The cast net shown in the figure of the fisherman is make of thread twisted by hand from pineapple fiber; and the hide in process of tanning has been treated with an infusion of the bark of *Pithecolobium dulce*, which, like the source of the leather itself, is an intrusion from America.

With the exception of a few families living in rancherias, the natives inhabit villages and go to their ranchos, or country places, for the purpose of feeding and watering their stock or for cultivating their fields. The town houses are well constructed; they are raised from the ground on substantial, durable posts, or built of masonry with a basement or "bodega," which is used as a storeroom, taking up the ground floor. Some of them are surrounded by balconies inclosed by shutters or by windows with translucent bivalve shells for panes. The roofs are either of thatch or tile, the best thatch being that made of the leaflets of nipa palm. Many of the houses are provided with gardens, in which grow perennial eggplants, red peppers, bananas, plantains, various kinds of beans, squashes, and ornamental and useful shrubs and trees, including lemons, limes, pomegranates, sour sops, and sugar apples (*Anona squamosa*). Frequently under the eaves, so as to receive the drippings from the roofs, are planted rows of bright-colored foliage plants; and among the fragrant-flowered species are the milleguas,[a] the Egyptian henna[b]—a great bush covered with flowers which bear a general resemblance to and have the odor of mignonette—and the Ilangilang tree,[c] from which the celebrated perfume is made.

Ranchos, as the country houses are called, may be constructed for the use of one or two persons or for a whole family. Many of them are intended only for temporary occupancy, the adjoining ground being allowed to lie fallow after crops have been raised on it for four or five years in succession. The usual form of a small rancho is that of a shed, with walls of cocoanut matting or woven reeds and a roof of cocoanut thatch. Half of the hut is taken up by a split-bamboo platform, raised about 2 feet from the ground. This is the family bed. Beneath it are penned up each night the youngest broods of chickens with their mothers, to protect them from rats, cats, and lizards. The larger fowls fly to the spreading limbs of a neighboring tree (the site

[a] *Pergularia odoratissima.* [b] *Lawsonia alba.* [c] *Canaga odorata.*



FIG. 1.—MODERN OUTRIGGER CANOE OF GUAM.



FIG. 2.—GUAM FISHERMAN WITH CASTNET OF PINEAPPLE FIBER.



GUAM. AN OX CART. WHEELS OF CALOPHYLLUM WOOD.

for a rancho is always selected near a suitable roosting tree), or upon the ridge of the roof, or perhaps on some convenient perch in the hut itself, where there are always four or five setting hens in baskets hung on the posts. Sometimes the whole family remains on the rancho during the week, returning to the town on Saturday evening, when a procession of ox carts a mile long may always be seen en route to the capital, so that their owners may be ready for early mass the next morning.

There are few masters and few servants in Guam. As a rule, the farm is not too extensive to be cultivated by the family, all of whom, even the little children, lend a hand. Often the owners of neighboring farms work together in communal fashion, one day on A's corn, the next on B's, and so on, laughing, singing, and skylarking at their work, and stopping whenever they feel like it to take a drink of tuba from a neighboring cocoanut tree. Each does his share without constraint, nor will one indulge so freely in tuba as to incapacitate himself for work; for experience has taught the necessity of temperance, and every one must do his share if the services are to be reciprocal. By the time the young men have finished their round, the weeds are quite high enough once more in A's corn to require attention again. In the evening they separate, each going to his own rancho to feed his bullock, pigs, and chickens; and after a good supper, they lie down for the night on a Pandanus mat spread over the elastic platform of split bamboo.

If wealth consists in the ability to gratify one's wants, the people of Guam may be called rich; and were it not for the frequent occurrence of hurricanes life on the island would be almost ideal. None of the natives depends for his livelihood on either commerce or a trade. There are men who can make shoes, tan leather, and cut stone for building purposes, but such a thing as a shoemaker, tanner, or mason who supports his family by his trade is unknown. In the midst of building a stone wall, the native who has consented to help do the work will probably say: "Excuse me, Señor, but I must go to my rancho for three or four days; the weeds are getting ahead of my corn." And when one wishes to get some lime, the native to whom he goes for it may say: "After I have finished gathering my cocoanuts for copra I will get my boys to cut wood and make a kiln. Never fear, Señor, you shall have the lime within six weeks."

The result of this condition of society is that when a father dies the wife and children are not left destitute, as would be the case if they depended on the results of his handiwork alone. The crops continue to ripen and are gathered in due time by the family; the weeds and worms are kept out of the tobacco; the coffee bushes bend each year under their weight of berries, and the cocoanuts, as usual, yield their annual dividend. Indeed, in most cases the annual income in pro-

visions is amply sufficient to keep the family supplied with its simple clothing, some flour and rice brought by the traders from Japan or America to exchange for copra, and perhaps a few delicacies, a ribbon or two, and a new picture of the patron saint to place in the little alcove of the side room, where the light is always kept burning.

While in Guam I knew of only one person on the island dependent upon charity, and she was an old blind woman without children or near relatives. Even blindness does not make beggars of the natives. On one occasion, while crossing the island to report on the suitability of a certain bay as a landing place for the proposed telegraph cable, I visited a house in which a man and his wife were both blind. He was engaged in twisting pineapple fiber into thread for cast-nets. The surrounding farm was in a flourishing condition—here a field of corn, there a patch of tobacco, a little farther away a grove of young cocoanuts set out evenly in rows; near the house a thicket of coffee bushes red with berries; about the door betel nuts drying in the sun; at the edge of the forest a cow, very much like an Alderney, tethered to a tree to keep her out of a neighboring patch of sweet potatoes, and in a newly cleared spot, where the stumps of trees were still standing, I saw a rich growth of taro and some yam vines twining up a circle of poles inclined against a tree.

A fine, strapping youth came in to prepare dinner. He was the son of the old people and had been born before they were stricken with the disease which caused their blindness. It was he who planted the garden, who cleared the forest, cared for the cow, the pigs, and chickens, and collected the betel nuts. He climbed a cocoanut tree near the house and brought in a bamboo joint full of tuba, delicious as cider just beginning to turn sharp, which, after putting across the top some leaves to strain it, he offered us with the manner of a Spanish caballero. The next day, on my return from the opposite shore of the island, he saddled the sleek little cow and insisted on my riding her back to the city, he and the little calf running along by my side as the cow trotted over the good roads, and wading through the deep mud, as our way led across marshy places overarched by great bamboos. On all the farms we passed the natives were planting cocoanuts. There were fields of corn, sweet potatoes, and tobacco. The young tobacco plants, recently transplanted, were each sheltered from the sun by a section of cocoanut leaf stuck into the ground at an angle. Everybody seemed contented and all had a pleasant greeting for the stranger. Some of the shy little children brought out by their parents to see us took my hand to kiss it, as is the custom in the island on the occasion of a visit from a dignitary of the church or state or the head of a family. It seemed to me that I had discovered Arcadia, and when I thought of a letter I had received from a friend asking whether I believed it would be possible to "civilize the natives," I felt like exclaiming, "God forbid!"

ORIENTAL ELEMENTS OF CULTURE IN THE OCCIDENT.[a]

By Dr. Georg Jacob.

The intimate cultural connection between the ancient peoples since the beginning of history is an undeniable fact. It is almost a truism that original ideas are but exceptions to the overwhelming number of reproduced ones, and yet even learned men are strongly disinclined to acknowledge indebtedness for elements of culture, lest it interfere with the pleasing thought of development within one's own narrow circle. It is but natural to delight in a structure built in the course of many years from the quarries of one's own field, but it is equally true that this sentiment rests on suppositions based on anything but facts. A migrating idea, in the purely ideal sphere at least, could remain the same only under the assumption of perfect identity of national characteristics and entire suspension of development. This not being the case, the variation of the contents of an idea among different peoples is no proof against its modification from without. Nor is it necessary to refute the strange yet common view that the possibility of the construction of an internal development makes the assumption of external influences unnecessary.[b]

In the religious field the victorious course of Christianity from East to West is not an isolated phenomenon. Not only did the Mithra cult pursue a similar course, but we continually see religious ideas from the Orient penetrating Occidental culture spheres. It is not difficult to trace to the influence of the old Persian Dualism[c] the

[a] Transiation, after revision by the author, of Östliche Kulturelemente im Abendland. Vortrag, am 4. Februar 1902, zu Erlangen gehalten und nachträglich erweitert von Dr. Georg Jacob, ao. Professor der morgenländischen Sprachen. Berlin: Mayer and Müller, 1902, pp. 24, gr. 800.

[b] Stave, in Über den Einfluss des Parsismus auf das Judentum, Haarlem, 1898, has fallen into both these errors.

[c] I was led to these views especially by the comparative study of Persian and Arabic poets. Notice, for instance, the frequency of the epithet *pâk* (clean) in connection with the name of Allâh in Persion poetry and search for Arabic parallels. Many Persian conceptions have survived in Mohammedan writings; thus the later Turkish Kyrk sual point to contact with middle Persian sources. On the other hand, old Persian conceptions were later forced into the Koran by connecting them with such words as sidra (Sûre 53, 14, 16), kauthar (108), sirât (37, 23), sâhira (79, 14).

antitheses between God and the devil, between this world and the other world, between clean and unclean, which were but gradually adopted into the monotheistic religions. Old Persian ideas, especially those pertaining to final things, as death, the judgment, and events connected therewith, pervade Christianity, Judaism, and Islam, and through the medium of the former reached even the heathen Icelanders, so that we again meet their ideas point for point in the Edda. We need only think of the world-tree (the tûbà of the Mohammedans=Yggdrasil), the well containing the miracle-working water at its foot (called al-Kauthar, often only al-haud, "the cistern"=Urd's well), the bridge of heaven (Avestan chinvat, Arabic as-sirât, old Norse Bifröst), but particularly the Dusk of the gods, which agrees in all points with the last judgment as described by Moslem theologians. Here we have the blowing of the horn, known from the Koran, which in the Edda is performed by Heimdall, and the wide plain (ârsat al-ârasât, or sahra-i-mehscher=Wigrid); the "beast of the earth," which is to come out from a rock fissure near Mecca, corresponds to Fenris, and Daggâl to the Antichrist and Loki. I could enumerate a long list of such parallels.[a] For some of their ideas the Persians may have received the first suggestions from the Babylonians, though it is at present the fashion to overestimate the Babylonian influences.[b] The world view of the Babylonians still survives in our seven days' week; in fact, only through this world view can the astrology of previous centuries be rightly understood. I have already called attention to it in my initial publication (1887). Winckler[c] has explained the symbolical number seven and the unlucky number thirteen from Babylonian conceptions. The latter have to the present day exercised a mighty influence upon our economic life, and thus on human culture in general, through the fact that for the ratio of silver to gold the old norm from the mint regulation of Darius remained in force till the fall of silver. Winckler[d] has shown that this relation represents the time of revolution of the planets corresponding to the two metals, the moon and sun; that is, 27:360 (=1:13⅓).

[a] Of the literature bearing on this subject may be mentioned: Kohut, Ueber die jüdische Angelogie und Dämonologie in ihrer Abhängigkeit vom Parsismus in Abhandlungen der Deutschen Morgenländischen Gesellschaft 4, 1866, and Was hat die talmudische Eschatologie aus dem Parsismus aufgenommen? in Zeitschrift der Deutschen Morgenländischen Gesellschaft 21, 1867; Ernst Böklen, Die Verwantschaft der jüdisch-christlichen mit der persischen Eschatologie, Goettingen, 1902. Compare also Elard Hugo Meyer, Völuspa, Berlin, 1899.

[b] So, for instance, Hugo Winckler, Die babylonische Kultur in ihren Beziehungen zur unsrigen (Leipzig, 1902), goes too far when he (p. 22) derives our clock face from the Babylonian double hour. The division in twelve hours rather goes back to the sun clock and is to be explained from the fact that the sun does not shine during the night. So also our bock beer (p. 43) has nothing to do with the signs of the Zodiac, but is due to corruption by popular etymology of Eimbecker Bier.

[c] Opus cit.

[d] Ibidem.

Even slight deviations from this norm caused in the nineteenth century the greatest crises. The real relation could only in most recent times prevail against the tradition.

But we can trace the connecting threads still further back. The Buddha legend as "Barlaam and Josaphat" was during the Middle Ages a book of edification to Christians, Jews, and Mohammedans, and at present the Hindu world view is beginning to play a rôle in the Occident through the medium of Schopenhauer[a] and the preaching of Buddhism by the theosophical societies.[b]

The literature which occupied our youthful minds, and influenced perhaps more than we are aware the development of our taste, originated to a great extent in the Orient, not only the Biblical narratives and the stories of the Thousand and One Nights, but also many of the tales which the uninitiated considers of German origin.[c] German lyric poetry, whose creations form an important part of the literary wealth of the people, was during the period of the flourishing of the church hymn predominantly under the influence of the Hebrew Psalter. And in the nineteenth century Hâfiz, less through Goethe's West-Östlichen Diwan than through Bodenstedt's Mirza Schaffy, which was printed in more than a hundred editions, exercised an influence upon our love poetry which can not be overestimated. The magic-lantern theater (ombres chinoise), especially cultivated by the Romanticists—magic-lantern plays were written, among others, by Justinus Kerner, and an afterplay to it by Uhland, Chr. Brentano, Achim von Arnim, Count Pocci—came from Italy to Germany in the seventeenth century, but was already flourishing in Egypt in Saladin's time and can be followed up till the eleventh century in east Asia.[d] Goethe borrowed the ideas for the prologue of his Faust from the old Hindu theater and the Book of Job.

Recently the court theaters of the most artistic city of Germany did not disdain to borrow from Japan the revolving stage, invented in 1700 by Namiki Schozos, a stage arrangement which with practical purposes combines ideal aims.

The most finished creations of architecture belong to the Middle Ages, as we come more and more to learn. No other style is capable like the Gothic of distributing the masses harmoniously and of transforming heavy masonry into light effects. The horizontal line

[a] An instructive comparison of the systems of this most popular philosopher with the systems of the Hindus is found in Max. F. Hecker's Schopenhauer und die indische Philosophie, Köln, 1897.

[b] So, for instance, Th. Schultze, Der Buddhismus als Religion der Zukunft, 2d edition, Leipzig.

[c] For example, compare Wilhelm Geiger, Die kulturgeschichtliche Bendeutung des indischen Altertums (inaugural address), Erlangen, 1901, p. 8.

[d] Compare G. Jacob, Das Schattontheater in seiner Wanderung vom Morgenland zum Abendland, Berlin, 1901.

of the antique is something which does not occur in nature, and a violent crossing of it and the flat roof are unæsthetic in the highest degree. The grand development of Gothic architecture is due to the many methods of overarching the columns which made the pointed arch possible. Now where does this element, which enabled our great masters to produce their wonderful creations, first appear as an artistic means of architecture? In the Mosque of Ibn Tulûn, at Cairo, which was erected between 876 and 878; but probably even earlier in the Miqyas (Nilometer), on the Nile island Rôda.[a] In art industry our dependence is still more apparent. With all our technical aids we are still far from attaining the noblest productions of the oriental textile industry. This is brought home to us, with regard to the Middle Ages, by the raiment of old German emperors bearing Arabic inscriptions, and with regard to the present time by examining the colors of genuine carpets, or the gloss of genuine Brussa silks. And as in textile industry China gave us silk, so also in ceramics that country taught us to produce the finest material—porcelain. But the influence of oriental art industry reaches far beyond the mere production of material. Every connoisseur of our modern decorative art knows that it owes most of its suggestions to Japan. "At the Paris exposition," the expert, Ad. Fischer, says, "everyone familiar with Japan could have convinced himself that the artists of the various countries often adopted the ideas of some Japanese artist. Thus, for instance, the porcelain factory of Roezendael appropriated the glorious flower and bird sketches of Schigemasa." Fortunately, we have learned at last to give the Eastern patterns a Western surrounding, but one familiar with Japanese art will frequently discern the exotic master even in the creations of modern naturalism, which again lovingly studies our own flora and fauna, for which the classicists lacked perception, so that we are justified in asking whether this whole tendency, which appeals to us as something native, does not after all owe its development to the intelligent study of a foreign culture.[b] One who saw the plates of the elegant Vienna edition of Schmoranz, Altorientalische Glasgefässe, which appeared in 1898 (e. g., XXIX), will recognize that also this branch of our modern art industry has, in its noblest creations, copied the Orient with greater luck than the antique. This opens wider vistas concerning the influence of the Orient through art industry. Thus Wilhelm Bode[c] points out how Venice, which in the fifteenth century reveled in the glory of Oriental carpets, matured the grandest school of colorists in painting, and indeed the

[a] Compare Franz-Pascha, Die Baukunst des Islam, Darmstadt, 1877, p. 11.

[b] A good survey of the character of Japanese art is given by Max Brinkmann, Kunst und Kunstgewerbe in Japan (lecture), Hamburg, 1883.

[c] Vorderasiatische Knüpfteppiche, Leipzig (1902), p. 4.

thought suggests itself that the eyes of the Venetian painters were trained in these surroundings. We leave out of consideration what the antique on its part owed to the Orient and will only refer, concerning the origin of the gem, to the result arrived at by Furtwängler, of Munich, the greatest expert in glyptics:[a]

> The glyptic is none of the spontaneous arts which arise and flourish everywhere where men attained a certain degree of culture. It seems, closely seen, to have one original home to which all the other cases of its appearance more or less directly go back, that is, Babylonia.

And the gems again remind me of the Oriental origin of the fabulous animals and heraldic emblems;[b] the double eagle is, as it is well known, Hittite.

The spirit, the forms, and products of the Orient everywhere pervade and transform our home. Before our windows blossom the tulip, the imperial lily, and the lilac, transmitted to us by the flower-loving Turks, to whom we probably also owe the horse chestnut. The eggs of the hen, a fowl originally from India,[c] and the spices and other products of the Tropics have become indispensable necessities for our kitchen. Even the old German millet-pap had to give way to the Arabic coffee. Nay, even our idle pastimes bear the stamp of Moslem custom, for we owe the games of chess, checkers, and playing cards[d] to the Mohammedans.

But let us turn our attention from these small matters to more important elements. The idea of phonetic writing, as is well known, had only one source. All the Indo-Germanic alphabets have a common origin in the North Semitic (Phœnician or, more correctly, the Canaanitish-Aramean). That also the South Arabic characters are but secondary forms of it was proven by Lidzbarskil,[e] notwithstanding the attempt to reverse the relation. Even the Devanâgarî script with its family goes back to the North Semitic source.[f] Wherein

[a] Antike Gemmen, vol. 3, 1900, p. 1.

[b] Edward Thomas Rogers, Le blason chez les princes musulmans de l'Égypte et de la Syrie: Bulletin de l'Institut égyptien (Séance du 24. déc. 1880) II. Série Caire 1882, pp. 83–131.

[c] The author of the strange book, Rembrandt als Erzieher, had the misfortune to contrast (24th edition, p. 43) the hen, as representative of the beautiful of our native fauna, with the parrot. The exceptions made by the Rembrandt philosopher to the colors of the parrot might also hold good with regard to the roller, which likewise remains a German bird.

[d] I have shown in the Zeitschrift der Deutschen Morgenländischen Gesellschaft 53 (1899), 349–350, that the Spanish "naipe"—playing card—is derived from the Arabic lâib, play.

[e] Der Ursprung der nord-und südsemitischen Schrift: Ephemeris für semitische Epigraphik, vol. 1, part 2. This methodically masterly treatise should form the starting point for all further investigations in the field.

[f] Compare G. Bühler, Indische Palaeographie (Grundriss der indo-arischen Philologie), Strassburg, 1896, p. 17 ff.

consists the cultural value of phonetic or letter writing? It is not, as many assume, in facilitating the reading, for psychophysics has experimentally established the fact that we, no less than the Chinese, read not letters but words. Moreover, anyone can easily convince himself of this by the inability to at once read fluently a sentence in an entirely foreign language.[a]

The circumstance that we read words explains the tendency to revert to ideographic writing which we can observe in all cursives and especially in the name chiffre whose dissolution into their letter constituents must be foregone. This is the only excuse for the mischief called orthography, which greatly nullifies the use of the invention by compelling us to express the same sound through different signs, as in German v and f and different sounds through the same sign, etc. Still, even in English, where a different vowel from the one meant is frequently written, letter writing has considerably simplified and facilitated the acquisition of reading, and that means the spread of culture. Its effect also reaches beyond the limits of nationality and age, and, finally, only through it could printing with movable type have become effective. To be sure, our writing is phonetically still far from perfect. The forms should in the first place indicate the articulation, and similar processes, such as modulation and aspiration, should be expressed by the formation of the letters themselves; further development of the sounds is conceivable which would render the writing simpler and more practical.

The invention of the letter alphabet which we owe to the practical sense of the Semites, and which was not essentially modified through the Classical and Christian Germanic culture periods, is such an important achievement that its historical aspect is worth consideration. To the spread of the Semitic alphabet in the regions known as its home, the find of Tell-el-Amarna furnishes the furthest limit in time, for as it proves that cuneiform writing was then in such exclusive use in Canaan that even the Canaanitish glosses are expressed in this cumbersome script, a Semitic consonantal writing could hardly have existed there prior to 1400 B. C.[b] The close relationship between the writing of the Moabite Stone (840 B. C.) and the old-Aramean monuments of Senjirili (eighth century B. C.) seems to establish a common origin which we can not well push back beyond the eleventh century B. C. I see, therefore, no cogent chronological arguments against the recently asserted hypothesis of the immigration

[a] The Greek ἀναγιγνώσκειν (properly, to recognize again) expresses, therefore, more correctly the process than the Latin "legere" and the German "lesen," which represent only the elementary phase of reading if legere suggests the collecting of the single letters and ἀναγιγνώσκειν the recognizing of whole words.

[b] Compare Lidzbarski, op. cit.

of the alphabet into Palestine with the Philistines from Crete.[a] As regards the inscriptions discovered by Evans[b] in Crete, even if, as asserted, they contained the mother script of the Canaanitish alphabet, and the clay tablet archives of Cnossus, from which the decipherment will probably have to start as soon as they are completely published, went back beyond the fourteenth century B. C.,[c] still we have in the Orient much older systems of writing, besides it is far from settled that the question is here of a purely letter alphabet. The very number 93 of the pictographs discussed by Evans is against this assumption. H. Kluge,[d] who reads them as Greek characters, had to employ arbitrary identifications of different signs in order to reduce their number. Of the many improbabilities of this attempt at decipherment may be mentioned the assumption that the original vowels became Semitic laryngal signs, while the opposite development appears as the only natural one. Furthermore, according to the original forms assumed by him for the Cretan lineal signs, they should have something in common with the later Greek writing in contrast to the Canaanitish, but on the contrary the dependence of the Greek forms on the Canaanitish has been proven with great acumen by Lidzbarski. The testimony of the ancients themselves that the letters of Cadmus went back to an Oriental hero would have little weight if it had not a strong support in the unmistakably Semitic names of the Greek characters.

In the Middle Ages another scarcely less grand achievement of the human mind was transmitted by the Saracenes to the Occident—the Arabic system of numerals. To estimate the importance of reducing to a consistent system the position value of the signs which rest on the invention of the Zero, we must recall the utter impossibility of calculating a logarithmic table with Greek or Roman numerals, and the absolute necessity of this auxiliary for all modern mathematical sciences. Even the simplest arithmetical operations, as division, could not possibly be carried on with the antique numerals, and it requires, indeed, a kind of fanaticism to prefer, even at present, on title pages such modes of writing as CIↃIↃCCCLXXXVIII, etc., instead of 1888.

The form of the Arabic ciphers exhibit in many directions remarkable relations. There was, of course, many attempts to refer them to an Occidental origin, but these attempts are to be taken still less seriously than those concerning letter script. The graphic evolution of the Arabic numerals from the Roman, defended with much skill by

[a] A. Fries, Die neuesten Forschungen über den Ursprung des semitischen Alphabets, Zeitschrift des Deutschen Palästina Vereins, xxii, 1899, 118–126.

[b] Arthur J. Evans, Primitive Pictographs and a pre-Phœnician script from Crete and the Peloponnese: The Journal of Hellenic Studies, xiv, London, 1894, pp. 270–372; Further Discoveries of Cretan and Ægean Script, ibid., xvii, 1897, pp. 327–395.

[c] Athenæum, May 19, 1900, p. 634.

[d] Die Schrift der Mykenier, Cöthen, 1897.

Sédillot,[a] is a mere play of fancy and can not be followed up historically, unless one should introduce as an argument for it the iii of the rock inscription of the tenth century at Tôr, near the Gulf Suez, written in Roman fashion immediately before the Arabic numerals.[b] On the other hand that the Divânî or Siyaqat ciphers, which show some similarities to the common Arabic numerals, arose from the abbreviated Arabic numerals, was already correctly recognized by De Sacy.[c] Nevertheless the Indian origin of the Arabic numerals, acknowledged by the Arabs themselves, can now be considered as absolutely certain.

Prinsep's view,[d] that the numerals of India developed from the initial letters of the corresponding numbers, does not take into account the possibility of accidental similarity between simple signs. As regards India ciphers 1–3, the formation through the corresponding number of strokes would at first suggest itself,[e] but foreign influence is probable. But our first task, laying aside conjectures, should be to collect all the data on the ciphers.[f] Woepcke's[g] assumption of a migration of the Indian ciphers during the second or third century to Alexandria is wholly improbable, and also devoid of any proof. Alexandria had no need for foreign numerals, and the India system, being at that time still without the symbol 0 (zero), had no material advantages over the antique. Rather, in their course to the west, we first meet the India numerals among the Arabs, the earliest documentary proof being furnished by the Fayum Papyrus, No. 798, of the Vienna collection of 260 A. H. (= 873–74 A. D.).[h] The west Arabic rather than the east

[a] Sur l'origine de nos chiffres, lettre de M. L. Am. Sédillot à M. le prince Balthasar Boncompagni. Extrait des Atti dell' Accademia pontificia de' Nuovi Lincei, Tomo xviii–Anno xviii Sessione Va del 2 Aprile, 1865, Rome, 1865, especially p. 6.

[b] Compare Zeitschr. der Deutsch. Morgenl. Gesellsch. 50, 1896, p. 90.

[c] Grammaire Arabe, 2d ed., vol. I, Paris, 1831, p. 91 and plate viii. Examples of the Siyaqat numerals are also found in the proceedings of the International Congress of Orientalists at Vienna, 1888, Semitic Section, pl. ii. Turkish MSS. of the Library of the Deutsche Morgenl. Gesellsch., No. 5, of the old catalogue (II, p. 39). The photograph of another Turkish document with Siakat ciphers, the original of which is in the Ethnographical Museum at Munich, was sent me a few days ago by Dr. Buchner. Count Eberhard von Mülinen, who first called my attention to this script and who kindly placed at my disposal some modern examples of it, refers me to Ismail Ghalib bin Edhem, Takvim-i-meskukiat-i-seldschukijje, Constantinople, 1309, p. 56.

[d] Journal of the Asiatic Society of Bengal, vol. vii, part 1, Calcutta, 1838, p. 348 ff.

[e] Compare Bühler, Indische Palaeographie, pl. ix.

[f] I refer to Euting's synopsis of the Aramean ciphers in his Nabatäische Inschriften, p. 96–97; Lidzbarski, Handbuch der nordsemitischen Epigraphik, p. 198 ff.; Gotthold Gundermann, Die Zahlzeichen, Giessen, 1899; on the evolution of cipher writing in India, Bühler, Indische Palaeographie, pl. ix.

[g] Mémoire sur la propagation des chiffres indiens: Journal Asiatique, Série vi, Tome 1, 1863.

[h] Comp. Karabacek, Führer durch die Ausstellung (Papyrus Erzherzog Rainer), pp. 216–217; for later proofs id. in Wiener Zeitschrift für die Kunde der Morgenlandes, xi, 1897, p. 13.

Arabic numerals resemble ours as well as those of India, because they have more faithfully preserved the old Arabic forms. The history of writing offers in this respect a parallel, since the Maghrib alphabet stands in many respects much nearer the Cufic than does the Neskhi. The ciphers of a Shiraz manuscript of the tenth century[a] shows the transition of the older Islamic forms into those at present in use in the East.

In earlier times the zero was represented by a point; the circular form is secondary. R. Hoernle[b] believes he recognizes the beginning of this sign in India in the fragments of an Indian arithmetic recently discovered, which he would ascribe to the third or fourth century A. D., and in which the point is also still employed for the unknown quantity. If it must be admitted that there is no inscriptional evidence for the zero before the eighth century, still there are indications of its existence in India even in previous centuries. I also believe that there is another series of phenomena connected with the history of the development of the zero which until now have not been considered under this aspect. The Greek philologians used at first to mark passages which they considered as not genuine by a horizontal line called ὀβελός. In the Hexapla of Origen the ὀβελός appears in various forms without any addition, as hypolemniscus with a point underneath, as lemniscus with two points, one above and the other underneath the line. As these signs are used promiscuously, those provided with points probably did not originate with Origen himself, but represent attempts at explanation by the scribes. The connection between the obelos points and the canceling point, which writers of different languages of the Orient and Occident place over letters which we would erase, is evident. In Latin this process was already in the fifth century in vogue.[c] As regards Greek,[d] Syriac, Armenian, I can only assert the fact without being able to fix the date of its beginning. In the Hebrew Old Testament, too, our texts mark every letter to be canceled by a point over it (compare, for instance, Genesis xvi, 5), and if an entire word should not be read the point is repeated over every letter of it (compare, for instance, Genesis xxxiii, 4). In Psalm xxvii, 3, is even found a mark corresponding to the lemniscus; that is, points above and under every letter. The mentioning of these points in the Talmud[e] shows that they are older than the Masoretic vowel

[a] Reproduced by Woepcke, op. cit., p. 75, column 4.

[b] On the Bakhshali manuscript, in the Proceedings of the VIIth International Congress of Orientalists at Vienna, 1886, Aryan section, pp. 131–132. Compare also M. Haberlandt, Zur Geschichte der Null. Oesterreichische Monatsschrift fur den Orient, Wien, 1890, vol. 16, pp. 158–160.

[c] Maurice Prou, Manuel de Paléographie latine et française du vi[e] au xvii[e], siècle, Paris, o. J. S., 151.

[d] Compare Gardthausen, Griechische Palaeographie, Leipzig, 1879, pp. 278–279.

[e] Der Babylonische Talmud übersetzt von Wünsche, 1. Halbband, Leipzig, 1886, p. 6.

system which the Talmud does not yet know. The circle (circellus) is met with in the Old Testament canon when the reading of the text is supplanted by a Masoretic marginal correction, which appears in our editions as a footnote. A small circle with negating force is also known to the Arabic popular script which arose in the period of the Omeyads. The well-known Arabic sign of vowellessness, called sukûn or jezma, is perhaps not an unimportant connecting link in the history of the zero. It differs, it is true, from the other cases in so far that it negates the vowel, not the consonant, but Nöldeke, in his Geschichte des Qorâns, page 316, has also adduced an instance of the latter; in the Cufic codex, Wetzstein, n. s., No. 5, a yellow zero appears as a canceling mark of a consonant.[a] In addition to the paleographical witnesses come also historical ones.

In a poem composed by a Bedouin during an expedition to Cyprus under the Calif Al-Walid Ibn Yazid (125–26 A. H. = 743 A. D.),[b] the author deprecated the sea voyage, which he would gladly exchange for a camel's ride, resigning wages and heavenly reward to others—if he had but firm land beneath his feet, he would at once desert: "Verily," he exclaims, "my name at the roll call will receive a circle." Positive evidence for the existence of the zero sign in the Occident and its Latin name cifra can be shown only since the twelfth century.[c] In the sixteenth century a division of meaning takes place so that the word in the form of "Zero" preserved the old signification of null (zero), while in that of "chiffre," cipher, it was used for any numeral.[d] While I readily agree with Krumbacher that the word sipos, which twice made its appearance in the Occident, can only be ψῆφος (psephos) I know of no phonetic Arabic parallel to the derivation of sifr from ψηφο(φο)ρία (psephophoria). Sifr occurs in the meaning of "empty," even in pre-Islamic time.[e] We shall therefore have to accept the old explanation[f] that Arabic sifr in the meaning of zero is a translation of the corresponding Indian sunya.[g] As in the case of the sign for no value, so also from the Orient comes the sign for the unknown value. Here, too, most desperate attempts were made to show its derivation from

[a] We employ the canceling points at an erased word and they refer then to the erasure.

[b] Noeldeke. Delectus veterum carminum Arabicorum, p. 62, Wellhausen. Die Kämpfe der Araber mit den Romäern in der Zeit der Umaijaden, p. 32.

[c] Comp. Karl Krumbacher, Wohher stammt das Wort Ziffer (chiffre)? in Psichari, Études de philologie néo-grecque (Bibliothèque de l'École des hautes études, 92) Paris, 1892, p. 347.

[d] Krumbacher, op. cit., p. 348.

[e] Comp. Hâlîm, ed. Schulthess, 31, 9, comp. also safira 'l-witâbu. Imruulquais. Ahlwardt 7, 3, Ibn al-Athîr, i, p. 379.

[f] Woepcke, op. cit., p. 522.

[g] A good survey of this question is given by Hermann Schubert, Zählen und Zahl: Virchow-Holtzendorff'sche Vorträge, Neue Folge, 2d series, part 13, Hamburg, 1887.

the antique culture sphere, and each theory had adherents. Thus, according to Prouhet, whom C. Henry still praises[a] for his "ingenious" idea, we must believe that our X was the Roman sign for 1,000, viz, ∞(=CIↃ), for one says: "He eats for 4," etc. One would expect that mathematicians, and especially arithmeticians, would be a little more precise in handling numbers and not write 1,000 for any other number. Lagarde, as is well known, has proven[b] that the X of the mathematicians is an abbreviation of the Arabic word shei, "a thing," "something," which as early as the eleventh century was used to designate the unknown, and which in the then prevailing Western transcription was rendered by xei and still appears in this form in Pedro de Alcala.

We have thus seen that two of the most important foundations of our culture, the alphabet and the ciphers, were gifts of the East. In order to obtain a more definite judgment of the share of the Orient and Occident in civilizing humanity, let us now turn to those discoveries and inventions which have contributed most to the mighty mental progress of the last centuries.

We begin to outgrow the ideals of so-called Humanism. Our age is in transition from classicism to universalism. Mental achievements are never formed from cloud mists, but need a concrete basis. The broad foundation of our modern world-view is the result of familiarity with the spirit of foreign civilizations, and these could enter into our horizon only after the invention of the compass, which made navigation on the ocean possible. The magnet needle was known to the Chinese even in the beginning of the second century A. D., the most important evidence of this fact being given in Klaproth's famous letter to Alexander von Humboldt. Sur l'invention de la bussole,[c] Ibn 'Adhârî quotes an Arabic verse of 854 A. D., in which the qaramît (=calamita) is mentioned in a connection which would imply its referring to the ship's compass.[d]

The work of civilization needs periods of peace. These we owe to the improvement of our military affairs, which have made war more terrible, but also less frequent. This, again, was made possible only

[a] Revue archéologique, Nouvelle Série, vol. 38, p. 5.

[b] Woher stammt das X der Mathematiker: Mittheilungen, Göttingen, 1884, vol. I., pp. 134–137.

[c] Paris, 1834 (abbreviated in German by A. Wittstein, Leipzig, 1885).

[d] Comp. Al-Bajânu' l-mughrib, ed. Dozy, Leiden, 1849–1851, vol. ii, p. 97; comp. p. 39 of the glossary. See also Journal Asiatique, vi, 11 (1868), p. 174 ff.; Steinschneider, Intorno ad alcuni passi d'opere del medio evo relativi alla calamita, Roma, 1871.—A. Schück (Hat Europa den Kompass über Arabien oder hat ihn Arabien von Europa erhalten?: Ausland, 65, 1892) is not acquainted with the important testimony of Ibn 'Adhârî, although it was to be found in E. Wiedemann, Über die Naturwissenschaften bei den Arabern, p. 20, and thus arrived at wrong conclusions, as the earliest Arabic information known to him dates from the thirteenth century.

by the invention of gunpowder, which gave to the intellectual element the sole mastery in warfare. The a priori conviction of many that only the Greeks or Romans could have invented gunpowder led to a dire confusion in this question. Combustibles like naphtha, etc., to which class also Greek fire belongs, were in use in the armies of the Califs[a] and were confounded with explosives. Marcus Graecus, who had a receipt for making gunpowder from saltpeter, coal, and sulphur, being credited to the ninth century, while he actually wrote about 1250, and this under Arabic influence. The monk Berthold Schwarz is naturally a counterpart to the pretended inventor of the compass, Flavio Gioja, the historical facts about both being in doubt. In any case, their lives are placed in a time when the inventions which they are said to have made had long been known. Those who would reconcile this discrepancy try to reserve for these men some improvement which they might have applied, but as a rule with little success. A critical sifting of the evidence begins only with Romocki's excellent history of explosives,[b] followed by a summarizing lecture by Dr. Edmund O. von Lippmann at Halle.[c] Both specialists arrived at the same conclusion, that saltpeter was first known in China, but not before about the middle of the twelfth century. We have old Chinese accounts of the brave and successful defense of the Chinese city of Pian-king (K'ai-fung) on the Lower Hwang-ho against the Mongols under Ogotai in 1232.[d] Here we first find explosives, blasting bodies, and rockets employed by the Chinese against the enemy. Of their form we get an idea from the cuts in Chinese fire books. In the thirteenth century the Arabs became acquainted with saltpeter, through China, for they designate it as thelg as-Sîn (Chinese snow), and the rockets as sahm Khatâî (Chinese arrow). In the fire book of Hasan ar-Rammâh (Paris National Library, de Slane's catalogue No. 2825 ff.), which originated between 1275 and 1295, saltpeter already forms the "basis of fireworks" (Romocki). The same Hasan ar-Rammâh for the first time describes a torpedo as baida takhrug wa-tahruq (an egg which comes forth burning) with a cut in one of the Paris manuscripts, reproduced by Romocki, p. 71.[e]

More important for us, however, than the compass and gunpowder

[a] Comp. on their naphtha division my Arabischer Berichterstatter, 3d ed., p. 66–67.

[b] S. J. von Romocki, Geschichte der Explosivstoffe: I. Geschichte der Sprengstoffchemie, der Sprengtechnik und des Torpedowesens bis zum Beginn der neuesten Zeit, Berlin, 1895.

[c] Zur Geschichte des Schiesspulvers und der Feuerwaffen, Zeitschrift für Naturwissenschaft, vol. 71, 1898, pp. 295–364.

[d] Fully translated by Stanislas Julien in Reinaud et Favé, Du feu grégeois, des feux de guerre et des origines de la poudre à canon chez les Arabes, les Persans et les Chinois: Journal Asiatique, octobre 1849, p. 284 ff., reprinted by Romocki, p. 45 ff.

[e] Comp. also Max Jähns, Handbuch einer Geschichte des Kriegswesens, Leipzig, 1880, p. 518 ff.; Geschichte der Kriegswissenschaften, München, 1889, i, pp. 179–182.

was another invention, I mean that of printing, on which in recent years new light has been shed, especially through the finds in Egypt. If printing now appears to us as the greatest achievement of civilization, the merit of the invention rests less on the fundamental idea than on two preliminary conditions which rendered it possible to be turned to account, and without which the process would have remained unpractical, namely, the manufacture of a cheap writing material and the phonetic system of writing by which the entire fund of language can be represented through two dozen signs. We shall see how the Orient can claim in all these elements a considerable share of glory. In the first place, as regards the fundamental idea of printing, it can hardly be called a feat of genius, for the idea already existed in the use of ancient seal signs and mint stamps. The Babylonians who, as is well known, used clay as writing material, knew a method of multiplying texts analogous to book printing. We have old oriental seal cylinders[a] covered with longer or shorter texts that were impressed in soft clay as the cylinders rolled over it. Writing materials of classical antiquity were too costly to make the general application of this process feasible. The art died out until East Asia solved the problem of material in a way before unsurpassed. As recently as 1875 Wattenbach, in the second edition of his Schriftwesen im Mittelalter (p. 114), said: "Paper * * * wraps its origin in thick darkness which will probably never be dissipated." How strangely this sentence now reads since the history of paper has come to be perhaps more unfolded to us than the history of any other ancient invention. We owe this progress above all to the fortunate circumstance that the greater part of the papyrus find in the Fayum came into the hands of investigators at Vienna who understood it well enough to make a scientific use of it, while the part which strayed to Berlin has contributed nothing to the numerous and surprising results gained in Vienna.

Ancient civilized nations at first used for writing materials what nature produced in a condition already suited to that purpose. So the Chinese formerly employed bamboo, as we can infer from the composition of some of the characters of their indeographic writings.[b] The employment of color contrast must also be considered as a step forward, for at first the signs were merely scratched, as was the custom of our ancestors. I surmise that the invention of the pit (or

[a] See Furtwängler, Antike Gemmen, vol. 1, plate 1; vol. 3, p. 1 ff. Illustrations are found, for instance, in Hommel's Geschichte Babyloniens and Assyriens. Before the coming of scarabs into use this form of seal prevailed also in Egypt. Furtwängler, op. cit. See Dyroff, Führer durch das Königliche Antiquarium in München, p. 109.

[b] Comp. for the following Friedrich Hirth, Die Erfindung des Papiers in China: T'oung Pao, Leiden, 1890, vol. i, p. i ff, reprinted, without Chinese types, in his Chinesische Studien, vol. i, p. 259 ff.

brush of rat's hair, which the Chinese still use instead of the pen) is connected through Mông-T'ien (died 209 B. C.)[a] with the appearance of a softer writing material which, according to Chinese accounts found in Hirth, was, even in pre-Christian time, made from silk scraps. About 100 A. D. Ts'ai Lun, the director of the imperial manufactory of arms, made his immortal invention. Finding silk too expensive and bamboo unhandy, he devised a new writing material and manufactured paper out of bark, hemp, rags, and fish nets. It is well known that paper can be obtained from various plant fibers by freeing them from foreign substances, vigorously stirring when in a moist condition and drying in thin layers. The older processes show a similarity to the manufacture of felt, except that felt is made from raw animal materials while the paper industry uses vegetable fiber. As felt manufacture was particularly at home among the East-Turkish nomads, it may be supposed that the suggestion for the preparation of paper came from them to China, the more so as we first of all hear of raw animal materials (silk scraps). The most important source on Ts'ai Lun is his biography in the annals of the later Han, which treats of the period of 25–220 A. D. The great importance of the new invention was already recognized in his lifetime, and succeeding years did not forget his merit. In 105 A. D. Ts'ai Lun was officially praised by a cabinet order, and his house and the stone on which he stamped his paper were for many centuries considered as celebrated sights.

To the Vienna orientalist, Hammer-Purgstall, belongs the merit of having first brought to light from Islamic sources the important account of the spread of Chinese paper by way of Samarkand to the West;[b] the precise date was established by Karabacek.[c] The most important source, Tha'âlibî's Latâif al-ma'ârif,[d] relates of the paper industry of Samarkand, which superseded papyrus and parchment, that it was transplanted thither by Chinese prisoners of war, captured by Ziyâd, son of Sâlih. There is a parallel account in Qazwînî's Âthâr al-bilâd.[e] Karabacek's somewhat free translation seems to me to have much obscured the meaning of the ittakhadha. I should render the quotation from Qazwînî: "The author of Kingdoms and Traveling-routes relates that prisoners of war from China were transplanted to Samarkand, among whom were some who understood the manufacture of paper and choose it," etc. The reference here is evi-

[a] I am indebted for this precise date to Professor Hirth, of Munich, whom I consulted in some cases about the transcribing of Chinese names.

[b] Zeitschr. der Deutschen morgenl. Gesellsch., vol. viii, 1854, p. 529.

[c] Comp. for the following Karabacek, Das arabische Papier, reprint from the second and third volumes of the Mittheilungen aus der Sammlung der Papyrus Erzherzog Rainer, Vienna, 1887, and Neue Quellen zur Papyrusgeschichte by the same, reprint from the fourth volume of the Mittheilungen, Wien, 1888.

[d] Edition of De Jong, p. 126.

[e] Edition of Wüstenfeld, p. 360.

dently to the Mukataba, or right of slaves to buy their liberty, for as infidel prisoners of war were by Islamic law retained as serfs until they could accumulate the necessary ransom, they had to be given an opportunity for carrying on a trade. In the present case some of the Chinese paper makers chose the paper industry. The enterprise was successful and became a permanent acquisition for Samarkand. Ziyâd Ibn Sâlih is therefore not to be considered a genius in economics who wished to turn the skill of the foreigners into the service of his own state. From both Arabic and Chinese sources, which agree even as regards the month, we learn that Ziyâd gained a great victory over the Turkish princes, who were waging war against each other, and the auxiliaries sent by the Chinese Emperor under the command of the Korean Kao Hsien-fa in July of 751. Only on this occasion could those prisoners of war have come to Samarkand.

The Barmecide Al Fadl Ibn Yahya, brother of the grand vizier Ga'far who is known from the Thousand and One Nights, had as governor of Khurâsân opportunities to become acquainted with the Samarkand paper and transplanted this industry, as is related by Ibn Khaldûn under the reign of Hârûn-ar-Rashîd, between 794 and 795 to Baghdâd. By this step the Barmecide acquired great praise for himself, the city of the Califs having taken the lead in paper manufactories that spread into all Islamic countries, as far as Spain. The Museum Erzherzog Rainer possesses two Arabic letters on rag paper (Nos. 917 and 918) of about 800 A. D., which are probably two specimens of the Bagdad paper factory a few years after its establishment. The excavations of M. A. Stein in Chinese Turkestan may have brought to light still older paper samples.[a] By a chronological sifting of the Fayum documents, the gradual use of paper in place of papyrus can be distinctly followed, and in the middle of the tenth century the latter is entirely superseded. At the beginning of the eleventh century we first meet in the Fustât bazar with packing paper[b] in place of the coarse papyrus of which Pliny, xiii, 23, says: Nam emporica inutilis scribendo involucris chartarum segestriumque mercibus usum præbet, ideo a mercatoribus cognominata.

In agreement with the account of Fihrist (p. 21) that the Khurâsân paper was made of linen, Wiesner's microscopic investigations have proved that cotton paper was not the predecessor of linen paper, as was formerly thought, but had never existed.[c]

For the further spread of paper in the Occident we have only Wat-

[a] So far only the preliminary report, London, 1901, is accessible to me.

[b] Comp. Karabacek, Das arabische Papier, p. 37. Perhaps the Egyptian document finds come from such packing paper stores for which the numerous documents of a private character would speak.

[c] J. Wiesner, Die Faijûmer und Uschmûneiner Papiere: Mittheilungen aus der Sammlung Erzherzog Rainer, vols. 2 and 3, Wien, pp. 179–260.

tenbach's compilation[a] from which it is difficult to obtain a clear view. Still, according to the data given by him, it seems that paper production came from the Arabs to Southern Europe in the twelfth century and in the fourteenth to Germany (p. 145). How thoroughly the invention, the history of which we have just sketched, now pervades all our relations in life is shown among other things by the cognomen of "paper age" given to our time. Borrowings of civilization have also their traces in the language. And indeed our paper measures, "quire" and "ream," go back to old-Arabic time. "Ream" is the Arabic rezma, "package," which passed into Spanish as resma, into Italian as risma, into German as ries, into French as rame. For "quire" the French say "main de papier," the Russian "dyest bumagi." Dest is the Persian word for hand and in Arabic also denotes a pan[b] and a measure.[c] On the other hand, for the material itself the languages of the Occident did not receive a new word but transferred the Egyptian designation of the older writing material to the new descendant which in common with the former is of vegetable nature, just as the name "pen" was inherited by the more perfect steel writing instrument.

Like the art of paper making, so also that of printing wandered from the Orient to the Occident in the form of fabric printing (Zengdruck). Nobody has thus far made a study of this industry in China; in fact, there is a general dearth of workers in the field of sinology. It is well known of the Dayaks of Borneo that they first cut the designs of their tattooings in wood, then, with the aid of a pigment, impressed it on the skin and performed the operation after this pattern.[d] We possess Egyptian fabric prints of the sixth century. What is perhaps the oldest sample comes, it is true, from the tomb of St. Cæsarius at Arles, but is very probably of Egyptian origin[e] and is preserved in the Germanic Museum at Nuremberg.[f] This same institution possesses a valuable collection of fabric prints of the sixth and seventh centuries, which Dr. Forrer, of Strasburg, excavated at Ikhmim, in Upper Egypt; also two fabric print models from the same place. A shred reproduced by Forrer[g] seems to represent the beginnings of the art in the Occident and dates, according to him, from the Carolingian

[a] Schriftwesen im Mittelalter, 3d edition, Leipzig, 1891.

[b] Comp. Fleischer, De glossis Habichtianis, Lipsiæ, 1836, pp. 13–14, und Les voyages de Sindebad le Marin, ed. Machuel, 2d éd. Alger, 1884, p. 13 of the Arabic text.

[c] Comp., for instance, Ibn at-Tiqtaqà, ed. Ahlwardt, p. 131; faakala ma'ahu destam mina' l-khubzi 's samidhi, he ate a dest of cracknels; in the Stambul Karagöz print, "Karagözün aktor olmasy," is read, p. 8, "bir desta kiat," a dest of paper.

[d] See Heinrich Schurtz, Urgeschichte der Kultur, p. 397, and the illustration of a tattooing stamp on p. 398.

[e] Comp. R. Forrer, Les Imprimeurs des Tissus, Strasbourg, 1898, p. 9.

[f] No. 1088 in Hampe's Katalog der Gewebesammlung des Germanischen Nationalmuseums, 1. part, Nuremberg, 1896.

[g] Die Kunst des Zeugdrucks, Strassburg, 1898, plate iii, No. 1.

period. In the succeeding centuries it was Germany that assiduously cultivated fabric printing in the Occident.[a]

Printing on paper arose in China as a consequence of paper invention. As early as 175 A. D. the text of the Chinese classics was posted on the outer walls of the university and impressions were taken of it. At the end of the sixth century printing was carried on in China with wooden plates, for at that time the remnants of the classical books were cut in wood by order of the founder of the Sui dynasty.[b] At an early period the Chinese invention migrated to Japan. On the beginnings of Japanese printing Satow gives a thorough study. We learn from it that in 764 the Japanese Empress Shô-toku ordered a million of small wooden pagodas, each containing an imprint of a passage from the Buddhist book Vimala nirbhasa Sûtra, to be distributed among the Buddhist temples and monasteries. The carrying out of this command was brought to an end in 770. A number of these pagodas have been rediscovered in the Horyu monastery at Yamato. They contain on long rolled-up strips Sanskrit texts, but in Chinese characters. Facsimiles so far exist only in Japanese works.[c] We also possess metal printing plates of the year 816, with Chinese signs in relief.[d] Hirth found a book offered for sale in China which was printed from plates in 1054 A. D., containing poems by a poet of the Sung dynasty, with a portrait of the author in woodcut.[e] For the succeeding centuries information on book printing in East Asia becomes more and more abundant.

Although the geographer Ritter pointed out the antiquity of the art of book printing in the monasteries of the Lamas,[f] no headway, it seems, has been made in fixing the dates of the old Tibetan prints, as the persons mentioned in them as the printers or patrons are otherwise unknown. According to the history of Buddhism in Mongolia, translated by Huth,[g] the first Tibetan copy of the Kanjur and Tanjur was

[a] In addition to the literature mentioned above, compare on calico printing Forrer, Die Zeugdrucke der byzantinischen, romanischen, gotischen und späteren Kunstepochen, Strassburg, 1894; Karabacek, Führer durch die Ausstellung (Papyrus Erzherzog Rainer), Wien, 1894, pp. 228, 229.

[b] Satow, On the early history of printing in Japan: Transactions of the Asiatic Society of Japan, vol. x, Yokohama, 1882, p. 48ff.

[c] Kwanko zattshô und Kokoku shobatsu.

[d] Reproduced in Shiuko zisshiu, vol. i.

[e] F. H., Old Chinese books: Journal of the China branch of the Royal Asiatic Society for the year 1885, New Series, vol. xx, Shanghai, 1886, p. 53.

[f] Erdkunde, 2d part, 2 book; Asien, vol. 1, 2d ed., Berlin, 1832, pp. 744–745.

[g] 'Jigs-med nam-mk'a aus dem Tibetischen herausgegeben, übersetzt und erläutert von Georg Huth, ii, Strassburg, 1896, p. 165; comp. Köppen, Die Religion des Buddha, ii, p. 277: "Tibet is, like Germany and China, a land of books. Much is being printed there and it has been so a long time back, for the printing press has been known to the inhabitants of the snow kingdom perhaps since the T'ang dynasty under which it was invented in China, but certainly since the Mongol period—that is, at least two centuries before it was known to the Europeans."

printed in Tibet during the reign of the Mongol King Pôyant'ô Khan (1311–1319). It contains the account of a pious man who emigrated to Mongolia and there became priest of the ruler mentioned above. "He sent from Mongolia a large quantity of perquisites for the printing of the bKa-'gyur and the bsTan-'gyur, but particularly a small box full of Chinese blacking. The Lama rejoiced over it. Bloghsal of dBus and others printed with the plates thus sent the bKa-'gyur and the bsTan-'gyur at T'ugs-k'u and recommended the placing of these copies in the Manyughosha temple at sNar-t'an. After that the copies of the Kagyur and Tan-gyur became very abundant."

Of the further spread of printing in the Occident nothing was known until a few years ago. On the other hand, it was well known that the Islamic Orient for a long time opposed the introduction of the printing press. Their opposition was founded on the apprehension—not officially acknowledged—that the hogs' bristles, which the Mohammedans always suspect in the brushes used for the cleaning of the types, might touch in the type the name of Allah. Even at present the Koran is not being printed in the Orient, and lithography is generally given the preference, and the Moslem prints by reason of the imperfect cleaning of the types are much inferior to those of the Jesuits in Beyrout. In Constantinople a printing establishment came in existence only in 1727 in consequence of a hatt-i-sherîf of the Sultan Ahmed III.[a] The accounts of the Euclid in Arabic, supposed to have been printed in the sixteenth century at Constantinople,[b] rests, as I have been able to ascertain in the library of the Deutsche Morgenländische Gesellschaft, on an erroneous interpretation of the statements on the last leaf of a folio edition at Rome in 1594.

Great, therefore, was the surprise when the Fayum find brought to light thirty Arabic plate prints from Egypt belonging to the tenth Christian century, two of them perhaps even to the ninth century.[c] In the excellent Führer durch die Ausstellung (guide to the exhibit) Karabacek declares, page 247, that "they are, as regards the cut of the forms and the process of printing, perfectly identical with the Chinese." But I must contradict him when he goes on to say, "Thus our collection preserves the oldest prints in the world so far known," for, as I have shown above, older Japanese prints were then known. The

[a] Of the prints of this oldest Turkish press the University Library at Erlangen possesses a description of America under the title of "Tarîkh al-Hind al-gharbî al-musammâ bi-hadith-i-new, Rama'an, 1142 A. H.," the Library of the Deutsche Morgenländische Gesellschaft Nazmizade's Turkish translation of Ibn 'Arabschâh's Tarîkh-i-Timur of the same year, as, also, Hadji Khalfa's Taqwîm at-tawârikh of 1146 A. H., and I personally have the Grammaire Turque of 1730 A. D.

[b] Dibbin, Ædes Althorpianæ, vol. 1, London, 1822, p. 127: "Euclides. Arabicé. Constantinop., 1588. A beautiful large copy of a very uncommon edition." * * * Comp. Graesse, Trésor, ii, p. 515.

[c] Comp. Österreichische Monatsschrift für den Orient, vol. 16, 1890, p. 167.

Arabic documents at Vienna are partly printed black on white, partly white on black; No. 929 is printed in red. In one case (No. 941) there are Coptic characters in addition to the Arabic. They are without any value as regards their contents. A printed piece of the Koran, reproduced by Karabacek in the Führer, page 248, shows that the Mohammedans were not then prejudiced in this respect.

The historical continuity of printing can not be proven with the same certainty as that of the use of paper. Still, to show that the knowledge of printing on paper remained alive in the Orient, the following witnesses can be adduced. According to Karabacek, who refers to Abû Shâma's Kitâb ar-raudatain,[a] the compulsory bank notes, each of one dinar, issued in 1147 in northern Syria, were produced by plate printing, and in the paper money printing bureau established in 1293 A. D. at Tebriz the work was carried on after Chinese patterns.[b] Furthermore, the Persian historian Rashîd-ed-dîn (died 1318 A. D.) gives a description of the Chinese process of printing.[c] We learn from this description the interesting fact that at that time editions of a certain number of copies were not printed, but the plates were kept under lock in the libraries. Anyone who wished to buy a book went thither and had an impression made. The cultural value of the edition should not be underestimated. Thus, for instance, the importance of book printing for the Reformation would have been much impaired by the old Chinese process of multiplying.

As long as paper had to be imported into the Occident it could not be cheap, because of limited means of communication in the Middle Ages. From Wattenbach[d] we learn that in Germany, at least, the use of paper became more general only after the fourteenth century. After paper production was established in the Occident we observe here, as among the Chinese and the Arabs, that printing followed in its train.[e]

The step from printing from plates to that with movable types was, with our phonetic system of only two dozen signs, still less a feat of genius than the invention of the printing process at large. In the Wegweisser durch das Germanische Museum, Nuremberg, 1901, page 147, the following passage occurs: "In recent time some think they

[a] Printed at Cairo 1287 A. H. = 1870–71 A. D.

[b] Comp. Karabacek, Neue Entdeckungen zur Geschichte des Papiers und Druckes: Österreichische Monatsschrift für den Orient, vol. 16, 1890, pp. 169–170.

[c] Comp. M. J. Klaproth, Lettre à M. le Baron A. de Humboldt sur l'invention de la boussole, Paris, 1834, pp. 131–132.

[d] Schriftwesen im Mittelalter, 3d ed., p. 149.

[e] Comp. T. O. Weigel und A. Zestermann, Die Anfänge der Druckerkunst, 2 volumes, Leipzig, 1866; Katalog frühester Erzeugnisse der Druckerkunst der T. O. Weigel'schen Sammlung, Leipzig, 1872; A. Essenwein, Älteste Druckerzeugnisse im Germanischen Museum: Anzeiger für die Kunde der deutschen Vorzeit, Nuremberg, 1872, columns 241–248; W. L. Schreiber, Vorstufen der Typographie: Gutenberg-Festschrift, Leipzig, 1900, p. 30 ff.

have found proofs that the Romans of the later periods of the Empire were acquainted with the art of printing with movable types, or that at least attempts in that direction were then made." I could find no light on this paragraph which is apt to stir up the emotion of the visitors. The statement is made in such a timid manner that one suspects it could stand the test no better than the analogous assertions discussed above. But it is true that Gutenberg was not the first in the Occident to conceive the idea of printing with movable types, for initials, prefixed letters, seem to have been early in use,[a] and the Dominican, Conrad Forster, born at Ansbach, was employing movable types at Nuremberg between 1437 and 1457 in bindings, copies of which are still extant at Leipzig, Nuremberg, and Würzburg.[b] Chinese sources name as the inventor of printing with movable types of clay the smith Pi-Shöng between 1041 and 1049 A. D.[c] Though we have no positive indications of a migration of this art to the West, still there recently came to light books in East Asia which had been printed with movable types long before Gutenberg. The oldest east Asiatic print from types which Satow personally examined dates from the period between 1317 and 1324; whether it is of Korean origin or Chinese can not be decided with certainty.[d] In a supplement to his study just referred to Satow describes Korean books printed from metal types,[e] which furnishes another proof for the priority of printing from types in East Asia. One of these, printed in 1409, contains, in an epilogue, an important contribution to the history of type printing, for in it the King of Korea relates how, having recognized the inadequacy of printing from wood plates, he had for the preservation of literature ordered the manufacture of copper types at his personal expense and that of his court and not at the expense of his subjects. The memorable epilogue, which is dated between December 14, 1403, and January 12, 1404, closes with prayers for the future prosperity of the undertaking. Still, even this most important of all human inventions could not thrive in its own home, since the Chinese ideographic writing required such a large mass of type material that it almost outweighed the advantages of the innovation. Only through our Semitic phonetic alphabet could the idea become the factor in civilization that it now represents.

[a] Schreiber, Gutenberg-Festschrift, pp. 67–68; Wattenbach, op. cit., p. 269.

[b] Comp. Franz Falk, Der Stempeldruck vor Gutenberg und Stempeldrucke in Deutschland; Gutenberg-Festschrift, pp. 73-79.

[c] Comp. Stanislas Julien, Documents sur l'art d'imprimer à l'aide de planches en bois, de planches en pierre et de types mobiles, inventé en Chine longtemps avant que l'Europe en fit usage; extraits des livres chinois; Journal Asiatique, iv, 9, Paris, 1847, p. 511ff.=Comptes rendus des séances de l'Académie des Sciences, Tome 21, Paris, 1847, p. 1005ff. (The Chinese types are given in the Journal Asiatique only.)

[d] Comp. Transactions of the Asiatic Society of Japan X Yokohama, 1882, p. 63.

[e] Further notes on movable types in Korea and early Japanese printed books, ibid., pp. 252–259.

If we now pass in review the preceding disquisitions and recall all the great world-transforming consequences of those achievements which we, without question, owe to the Orient, we shall have to acknowledge that they form the presuppositions of a very important part of our mental life. Of course, our civilization is for all that no more oriental than antique. Each people lives its own life of culture; only impulses come from the outside. To gain a right estimate of their importance we must not allow ourselves to be misled by enthusiastic phrases, but, standing on the solid ground of facts, investigate how far the effect of the impulses reach, particularly whether they touch only a caste or the mass. While Hellenism did not reach the people—a Greek name in a popular song would at once characterize it as not genuine[a]—but continues its existence chiefly within certain scholastic circles, the usefulness of the compass, apart from indirect ways, directly benefits the entire seafaring population, and the advantages of explosives are appreciated by every soldier, while writing and printing may be considered as the common property of all mankind.

We do not cultivate the languages of the Orient because of the mighty influence of its people over the Occident in centuries past, but because we hope from these studies there may come even greater benefits in the future. As Humanism once meant a considerable widening of the mental horizon, so it means at present for our state of civilization an artificial narrowing, having crystalized into a cold classicism[b] and, according to the well-known law of human development, resembling in many respects the old scholasticism which it once conquered. But we expect, analogous to the Humanists, that our science, after removal of certain external obstacles which of late have hindered its progress, will have the mission, in union with other sciences which are more and more being developed from decade to decade, to deliver mankind from a one-sided world view and to give it back the understanding for the beautiful in all its manifoldness.

[a] Entirely erroneous is the theory propounded at present that popular poetry arises solely from the more or less learned class. Where is the art form of the drawing-room from which, for instance, the popular ditties ("Schnaderhüpfel") could have developed? There is only so much truth in this theory that no hard and fast lines can be drawn between both, and that they frequently influence one another, though the really good comes more often from below than from above.

[b] The enrichment through subjective assimilation of foreign elements is the latest phase of development which is as yet in its beginning.

THE NILE RESERVOIR DAM AT ASSUÂN.[a]

By Thomas H. Means,
In charge of United States Soil Survey, Department of Agriculture.

Egypt has probably been farmed for over seven thousand years. Until the present century practically all the farming done was by basin irrigation, which system consists in flooding large areas of land surrounded by dikes with water taken from the Nile River during time of flood. These basins vary in size from less than 5 acres to over 50,000 acres, and in a normal flood year are filled with water to an average depth of 4 feet for a period of about six weeks, after which the water is drained away and the seed sown in the newly deposited mud without cultivation. Such a system of irrigation is very wasteful of water and permits the growth of but one crop per year.

About 1820 Mohammed Ali, the reigning viceroy, started a movement which has almost revolutionized the agriculture of Egypt. He dug canals from the Nile, so that water could be had for irrigation throughout the year, permitting the growing of such crops as cotton, which would not mature under basin irrigation, and, what is more important, enabling two and sometimes three crops to be grown each year. To-day, of the 6,250,000 acres of arable land in Egypt, less than 2,000,000 acres are watered by the ancient basin system.

While this change is more economical of water it necessitates a more uniform supply throughout the season. The Nile can always be depended upon to supply 8,000 cubic feet per second, but for the complete development of the modern or perennial system of irrigation at least 30,000 cubic feet per second are needed throughout the year. During flood season the Nile frequently discharges from 300,000 to 500,000 cubic feet per second.

To conserve this flood supply for use during seasons of low water, a system of storage dams and regulators at various points on the Nile

[a] Reprinted, by permission, from Forestry and Irrigation, Washington, D. C., Vol. VIII, No. 12, December, 1902. [Formally dedicated December 8—A new type of structure which may mark an epoch in irrigation engineering—Photos furnished by the author through courtesy of the Egyptian Government.]

has been planned. As early as the time of Mohammed Ali this plan was under consideration, but it was not until Mr. W. Willcocks was appointed director-general of reservoirs that the storage of water on the Nile was thoroughly considered.

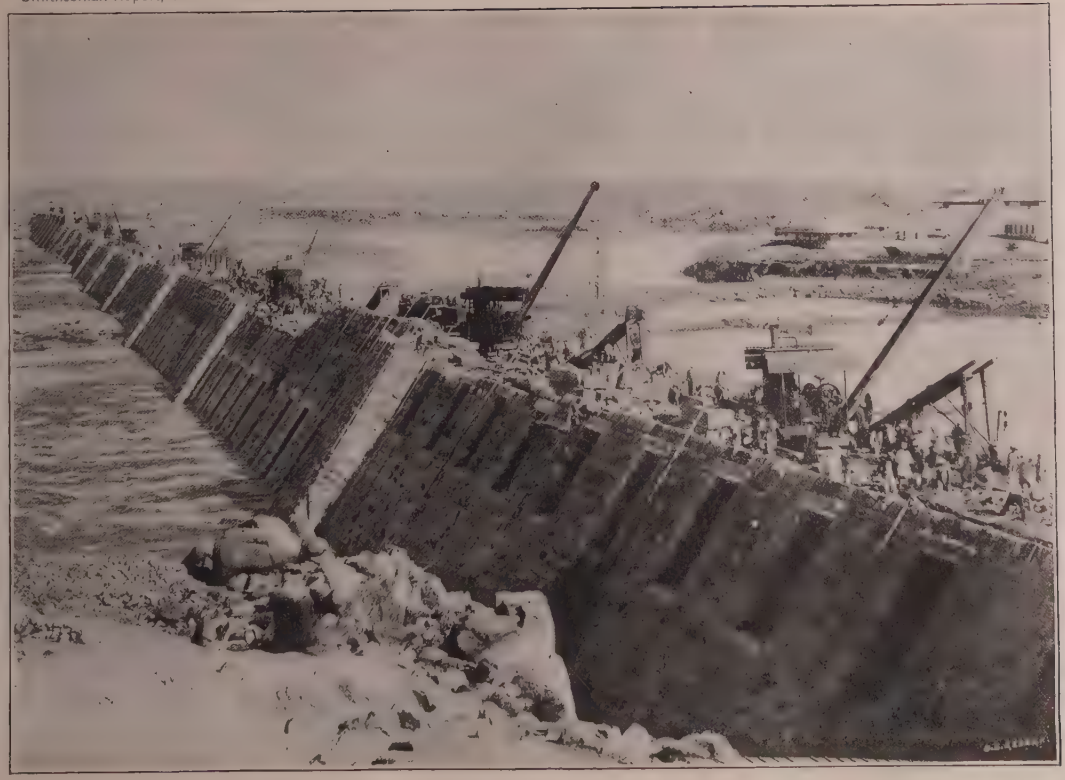
In 1890 Mr. Willcocks presented a report on the subject to the Egyptian Government, in 1894 issued a second report, and in 1895 a final report, with plans and estimates. The central feature of this system of flood control provides for a dam across the Nile at the head of the first cataract, or 5 miles above the town of Assuân. In 1898, a short time after Mr. Willcocks had left the service of the Egyptian Government, contracts were signed by Sir John Aird & Co. for the construction within five years of the Assuân dam, upon the plans prepared by Mr. Willcocks. Sir Benjamin Baker acted as consulting engineer, and Mr. Maurice Fitzmorris was appointed resident engineer.

The dam as completed during the present summer conforms almost throughout to the plans of Mr. Willcocks. His original plans provided for the construction of a dam following the line of soundest rock across the stream, with 60 undersluices having an area of 21,500 square feet, or sufficient to carry off the maximum floods of the river. In the plan of 1894, 100 undersluices were provided of the same capacity. In the final design there are 140 undersluices, each 23 by 6½ feet, and 40 at a higher level, 11½ by 6½ feet, giving a sluiceway of 24,000 square feet.

The question of the height of the dam involved a vexatious problem; the island of Philæ, which lies just above the cataract, contains some of the best preserved temples and buildings of ancient Egypt. Mr. Willcocks' plan of a dam, 100 feet above the zero of the Assuân gage, with a capacity of 85,000,000,000 cubic feet of water, would submerge these temples to a depth of 26 feet for a portion of each year. In his book upon the dam, Mr. Willcocks says: "The International Commission held widely divergent views about Philæ temple. M. Boulé refused to have anything to do with a project which in any way deranged the temple. Signor Torricelli said that he had been asked his opinion about the dam, and about the dam he would give his opinion, regardless of temples and antiquities, which were outside his province. Sir Benjamin Baker proposed raising the whole temple, like a great Chicago hotel, clean above the high level of the reservoir. Savants and antiquaries, and many who were neither savants nor antiquaries, but to whom Philæ offered an easy opportunity of obtaining notoriety, all joined in the fray. Eventually, in a moment of great weakness, the Egyptian Government, buoyed up by a succession of good summers, accepted the lowering of the level of the reservoir, so that only a part of Philæ temple should be drowned. The new reservoir level was to be 26 feet below that hitherto proposed, and the capacity of the reservoir was to be reduced from 85,000,000,000



THE ASSUAN DAM IN COURSE OF CONSTRUCTION—FILLING IN THE EXCAVATIONS WITH MASONRY.



AT WORK ON THE SUPERSTRUCTURE—THE DAM NEARING COMPLETION.

to 35,000,000,000 cubic feet of water. Fortunately the conditions of stability laid down by the International Commission on the initiative of Signor Torricelli were so severe that I was able to design a dam nominally capable of holding up 35,000,000,000 cubic feet of water, but actually strong enough to hold up 70,000,000,000."

The dam is located 5 miles south of Assuân, or about 550 miles south of Cairo, at the head of the first cataract. At this point the Nile falls about 16 feet in 4 miles, the bed of the river being granite rock. The fall is so slight that the cataract through most of the year is practically no more than rapids. The Nile boats go down the rapids and are towed up at nearly all stages of the river.

The dam is almost exactly one and a quarter miles long and has a maximum height above the foundation of 147 feet. The foundation was laid upon solid granite throughout. The rock was decomposed to a great depth; in some cases as much as 45 feet were removed before solid rock was found. This large amount of excavation increased the actual cost of the work beyond the original estimate. No drill holes were made in the underlying rock before the work of construction was commenced, so that the information upon which the original estimate was made was not as complete as it might have been in this respect. The dam is 23 feet wide at the top and allows for a roadway 13 feet wide, on which is laid a narrow-guage track. The rock is granite, quarried near by, and laid in Portland cement. It is said that 600,000 barrels of cement were used in this masonry—an order sufficiently large to materially affect the market value of cement in England. It is interesting to note that although the volume of masonry is very large, yet it approximates only one-fourth of the cubic contents of the Great Pyramid near Cairo.

The building of the dam was rendered especially difficult by the high floods which annually come down the Nile. The normal difference in level between high and low water at Assuân is 38 feet, and work could be carried on to advantage only during low water.

To expose a portion of the river bed, dikes were built, and the portion of the bed thus laid bare was excavated to solid rock. The foundation was then built up to about normal flood level, and a new portion of the bed dried. In this manner the foundation was completed across the river, and later the superstructure was added to the desired height. As will be seen by the accompanying illustrations, there was a great deal of hand labor, as many as 12,000 workmen being employed at one time, about one-tenth of whom were skilled Italian masons.

The sluices are arranged in tiers at three levels. Iron gates of the Stoney system, running on rollers in steel grooves, permit the closing or opening of all the sluices in a very few moments, the gates being suspended on steel wire cable and falling by their own weight. The winches are operated by hand. A few of the sluices are lined with

iron, but the greater number are lined with dressed granite blocks of large size.

Around the western end of the dam a ship canal 32 feet wide, with four locks, has been completed. This canal added very materially to the total cost of the dam. The gates in the canal are said to be constructed on plans drawn for lock gates on the proposed Nicaraguan Canal.

The sluice gates in the dam are opened during the first part of the flood season. In this time the muddiest part of the flood passes through the dam. As the river commences to fall—and fortunately the water carries much less sediment at that time—the gates are gradually lowered. As the flood subsides, a portion of the water is thus held up, and when the season of low water arrives, with its consequent scarcity in the perennial canals lower down the river, the reservoir is full. Then the gates are slowly opened, and as the river continues to fall the reservoir supply is drawn upon and the flow downstream from the dam maintained sufficiently to irrigate the desired acreage of land. The flow out of the dam is arranged so that the reservoir will be empty and the gates of the sluices open when the flood again comes down the river. There are no canals of large size taken from the river near the dam, so the water which is stored is turned into the river and taken out again farther down the stream.

By this system of managing the gates in the sluices, it is hoped to allow the greater part of the muddy water to go below the dam and to store the clearer waters of the later part of the flood. These later waters are known to be much clearer and to carry a sediment which will remain in suspension for a long time; yet the problem of silt in this reservoir is a serious one and the results which are obtained from this type of dam will be watched with interest by American irrigation experts.

The reservoir as now completed has a capacity of 800,000 acre-feet, or, according to Mr. Willcocks, enough water to irrigate 600,000 acres of cotton and sugar cane. As has been stated, this water is not to be used for the extension of the irrigated area in Egypt, but is intended to be used in extending the area of perennially irrigated land at the expense of the area under basin irrigation.

The cost of the dam can not be stated accurately. The original estimate was $8,750,000, but this sum was exceeded. The total cost to date is between the above sum and $10,000,000, making the cost about $12.50 per acre-foot. The value of this water to Egypt is said to be $100,000,000, or ten times the actual cost.

The Assuân dam is but one of a large number of engineering works planned for the complete subjugation and control of the Nile. It is hoped to build weirs and controlling works on the Nile at a number of points above Assuân for the irrigation of desert land in the Sudan and

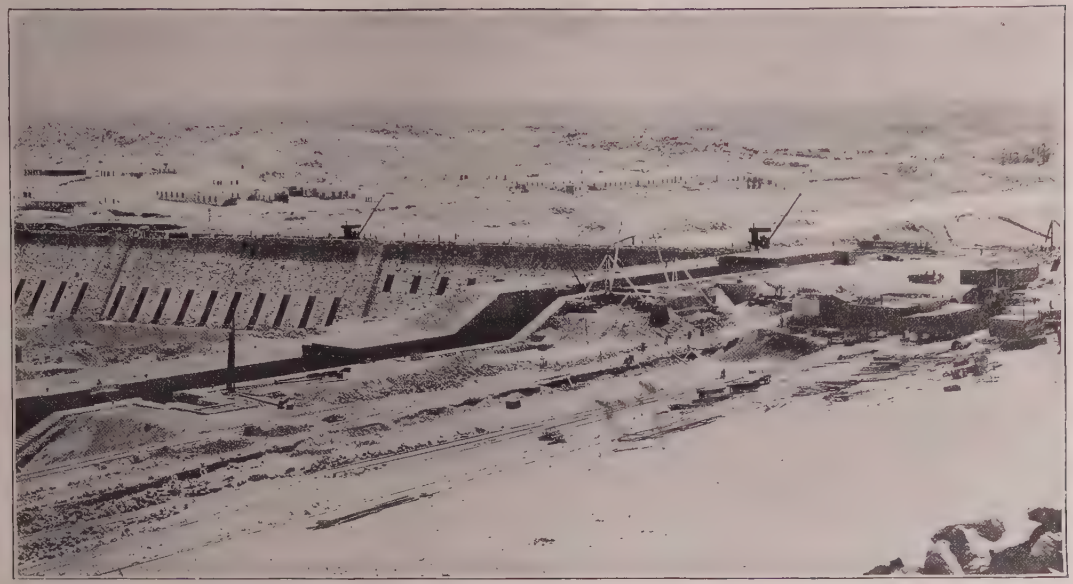


LOCK GATE ON THE SHIP CANAL AROUND THE DAM, BUILT FROM DESIGNS MADE FOR THE NICARAGUA CANAL.



BUILDING THE SHIP CANAL.

This view gives an excellent idea of the vast amount of hand labor.



THE SHIP CANAL WHICH PROVIDES FOR NAVIGATION AROUND THE DAM.



WATER FLOWING THROUGH THE UPPER TIER OF SLUICES, DOWNSTREAM SIDE.

Photograph reproduced through the courtesy of the Bureau of Soils, U. S. Department of Agriculture.

Central Africa. Below Assuân a weir has already been built at Assiut and one is under construction at Zifta. These weirs are designed to raise the level of the Nile at low water to fill the irrigating canals already in operation or to be constructed. As a safety valve, to let the highest and destructive floods escape, a plan is under consideration to construct a canal to Wady Rayan, a depression in the Sahara to the west of the Nile Valley, and drain into it the excess of water which would otherwise damage Middle and Lower Egypt.

To again quote from Mr. Willcocks:

"The Assuân dam is a work of a type designed for the conservation of the flood waters and which is new in the world. If successful it will mark an epoch in dam building. There must be sites on the torrential rivers of the arid and semiarid regions of South Africa, Australia, and North America, where dams of the type of the one at Assuân will supply a want which has long been recognized.

"A reservoir dam, which will allow the earlier floods laden with deposits a free and unimpeded passage and which will afterwards captivate the comparatively clear waters of the terminal inundations and early percolations and store them for subsequent use, ought to put new life into many abandoned projects for perennial irrigation. But the provision of perennial irrigation is not the only object for which this type of dam may be employed. Provided with its numerous flood openings, it may be looked upon as a weir capable of controlling the mightiest rivers in flood just as ordinary weirs control them in times of low supply; it may thus be utilized for the regulation of flood supplies of rivers and for their employment in basin or inundation irrigation. As designed for Assuân, its use is restricted to sites where broad platforms of sound rock can be counted upon, but designed in 'bèton armée' or 'ribbed concrete.' I hope to see it utilized in narrow gorges and throttled valleys, where £20 will go as far as £50 in a broad platform."

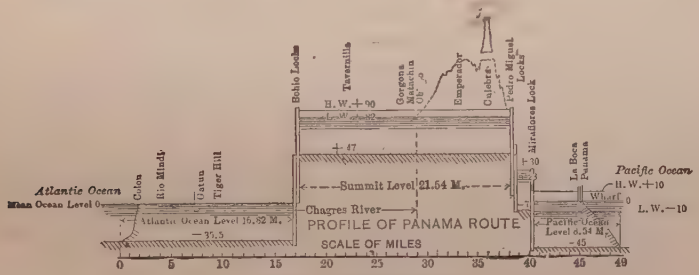
Unfortunately, in America the characteristics of our rivers, their floods and the amount of sediment carried, are not as well known as they should be; but each year adds volumes to our knowledge of these streams, and by the time any extensive system is to be put in operation our knowledge will be much more complete.

THE PANAMA ROUTE FOR A SHIP CANAL.[a]

By William H. Burr.

The Panama route as a line of transit across the Isthmus was established, as near as can be determined, between 1517 and 1520. The first settlement, at the site of the town of old Panama, 6 or 7 miles easterly of the present city of that name, was begun in August, 1517. This was the Pacific end of the line. The Atlantic end was finally established in 1519 at Nombre de Dios, the more easterly port of Acla, where Balboa was tried and executed, having first been selected, but subsequently rejected.

The old town of Panama was made a city by royal decree from the throne of Spain in September, 1521. At the same time it was given a



Profile of Panama route.

coat of arms, and special privileges were conferred upon it. The course of travel then established ran by a road, well known at the present time, through a small place called Cruces on the river Chagres, about 17 miles distant from Panama. It must have been an excellent road for those days. Bridges were even laid across streams, and the surface was paved, although probably rather crudely. According to some accounts it was only wide enough for use by beasts of burden, but some have stated that it was wide enough to enable two carts to pass each other.

The harbor of the Atlantic terminus at Nombre de Dios did not prove entirely satisfactory, and Porto Bello, westerly of the former

[a] Reprinted, by permission, from "Ancient and Modern Engineering and The Isthmian Canal," by William H. Burr, professor of civil engineering in Columbia University, New York. Published by John Wiley & Sons, New York, 1903. Copyright, 1903, by William H. Burr.

point, was made the Atlantic port in 1597 for this isthmian line of transit. The harbor of Porto Bello is excellent, and the location was more healthful, although Porto Bello itself was subsequently abandoned, largely on account of its unhealthfulness.

As early as 1534, or soon after that date, boats began to pass up and down the Chagres River between Cruces and its mouth on the Caribbean shore, and thence along the coast to Nombre de Dios and subsequently to Porto Bello. The importance of the commerce which sprang up across the isthmus and in connection with this isthmian route is well set forth in the last paragraph on page 28 of the Report of the Isthmian Canal Commission:

> The commerce of the isthmus increased during the century and Panama became a place of great mercantile importance, with a profitable trade extending to the Spice Islands and the Asiatic coast. It was at the height of its prosperity in 1585, and was called with good reason the tollgate between western Europe and eastern Asia. Meanwhile the commerce whose tolls only brought such benefits to Panama, enriched Spain, and her people were generously rewarded for the aid given by Ferdinand and Isabella in the effort to open a direct route westward to Cathay, notwithstanding the disadvantages of the isthmian transit.

This commercial prosperity suggested to those interested in it, and soon after its beginning, the possibility of a ship canal to connect the waters of the two oceans. It is stated even that Charles V directed that a survey should be made for the purpose of determining the feasibility of such a work as early as 1520. "The governor, Pascual Andagoya, reported that such a work was impracticable and that no king, however powerful he might be, was capable of forming a junction of the two seas or of furnishing the means of carrying out such an undertaking."

From that time on the city of Panama increased in wealth and population in consequence of its commercial importance. Trade was established with the west coast of South America and with the ports on the Pacific coast of Central America. In spite of the fact that it was made by the Spaniards a fortress second in strength in America only to old Cartagena, it was sacked and burned by Morgan's buccaneers in February, 1671. The new city, that is, the present city, was founded in 1673, it not being considered advisable to rebuild on the old site.

The project of a canal on this route was kept alive for more than three centuries by agitation sometimes active and sometimes apparently dying out for long periods, until there was organized in Paris, in 1876, a company entitled "Société Civile Internationale du Canal Interocéanique," with Gen. Etienne Türr as president, for the purpose of making surveys and explorations for a ship canal between the two oceans on this route.

The work on the isthmus for this company was prosecuted under the direction of Lieut. L. N. B. Wyse, a French naval officer, and he



FIG. 1.—VIEW OF THE HARBOR OF COLON.



FIG. 2.—THE PARTIALLY COMPLETED PANAMA CANAL, ABOUT EIGHT MILES FROM COLON.



FIG. 1.—THE EXCAVATION OF THE BOHIO LOCK SITE.



FIG. 2.—THE EASTERN FACE OF THE CULEBRA CUT.

obtained for his company in 1878 a concession from the Colombian Government, conferring the requisite rights and privileges for the construction of a ship canal on the Panama route and the authority to do such other things as might be necessary or advisable in connection with that project. This concession is ordinarily known as the Wyse concession.

A general plan for this trans-Isthmian canal was the subject of consideration at an international scientific congress convened in Paris in May, 1879, and composed of 135 delegates from France, Germany, Great Britain, the United States, and other countries, but the majority of whom were French. This congress was convened under the auspices of Ferdinand de Lesseps, and after remaining in session for two weeks a decision, not unanimous, was reached that an international canal ought to be located on the Panama route, and that it should be a sea-level canal without locks. The fact was apparently overlooked that the range between high and low tides in the Bay of Panama, about 20 feet, was so great as to require a tidal lock at that terminus.

A company entitled "Compagnie Universelle du Canal Interocéanique" was organized, with Ferdinand de Lesseps as president, immediately after the adjournment of the international congress. The purpose of this company was the construction and operation of the canal, and it purchased the Wyse concession from the original company for the sum of 10,000,000 francs. An immediate but unsuccessful attempt was made to finance the company in August, 1879. This necessitated a second attempt, which was made in December, 1880, with success, as the entire issue of 600,000 shares of 500 francs each was sold. Two years were then devoted to examinations and surveys and preliminary work upon the canal, but it was 1883 before operations upon a large scale were begun. The plan adopted and followed by this company was that of a sea-level canal, affording a depth of 29.5 feet and a bottom width of 72 feet. It was estimated that the necessary excavation would amount to 157,000,000 cubic yards.

The Atlantic terminus of this canal route was located at Colon, and at Panama on the Pacific side. The line passed through the low grounds just north of Monkey Hill to Gatun, 6 miles from the Atlantic terminus, and where it first met the Chagres River. For a distance of 21 miles it followed the general course of the Chagres to Obispo, but left it at the latter point and passing up the valley of a small tributary cut through the continental divide at Culebra, and descended thence by the valley of the Rio Grande to the mouth of that river where it enters Panama Bay. The total length of this line from 30 feet depth in the Atlantic to the same depth in the Pacific was about 47 miles. The maximum height of the continental divide on the center line of the canal in the Culebra cut was about 333 feet above the sea, which is a little higher than the lowest point of the

divide in that vicinity. Important considerations in connection with the adjacent alignment made it advisable to cut the divide at a point not its lowest.

Various schemes were proposed for the purpose of controlling the floods of the Chagres River, the suddenness and magnitude of which were at once recognized as among the greatest difficulties to be encountered in the construction of the work. Although it was seriously proposed at one time to control this difficulty by building a dam across the Chagres at Gamboa, that plan was never adopted, and the problem of control of the Chagres floods remained unsolved for a long period.

It was estimated by De Lesseps in 1880 that eight years would be required for the completion of the canal, and that its cost would be $127,600,000. The company prosecuted its work with activity until the latter part of 1887, when it became evident that the sea-level plan of canal was not feasible with the resources at its command. Changes were soon made in the plans, and it was concluded to expedite the completion of the canal by the introduction of locks, deferring the change to a sea-level canal until some period when conditions would be sufficiently favorable to enable the company to attain that end. Work was prosecuted under this modified plan until 1889, when the company became bankrupt and was dissolved by judgment of the French court called the Tribunal Civil de la Seine, on February 4, 1889. An officer, called the liquidator, corresponding quite closely to a receiver in this country, was appointed by the court to take charge of the company's affairs. At no time was the project of completing the canal abandoned, but the liquidator gradually curtailed operations and finally suspended the work on May 15, 1889.

He determined to take into careful consideration the feasibility of the project, and to that end appointed a "commission d'études," composed of eleven French and foreign engineers, headed by Inspector-General Guillemain, director of the École Nationale des Ponts et Chaussées. This commission visited the Isthmus and made a careful study of the entire enterprise, and subsequently submitted a plan for the canal involving locks. The cost of completing the entire work was estimated to be $112,500,000, but the sum of $62,100,000 more was added to cover administration and financing, making a total of $174,600,000. This commission also gave an approximate estimate of the value of the work done and of the plant at $87,300,000, to which some have attached much more importance than did the commission itself. The latter appears simply to have made the "estimate" one-half of the total cost of completing the work added to that of financing and administration, as a loose approximation, calling it an "intuitive estimate;" in other words, it was simply a guess based upon such information as had been gained in connection with the work done on the Isthmus.

By this time the period specified for completion under the original Wyse concession had nearly expired. The liquidator then sought from the Colombian Government an extension of ten years, which was granted under the Colombian law dated December 26, 1890. This extension was based upon the provision that a new company should be formed and work on the canal resumed not later than February 28, 1893. The latter condition was not fulfilled, and a second extension was obtained on April 4, 1893, which provided that the ten-year extension of time granted in 1890 might begin to run at any time prior to October 31, 1894, but not later than that date. When it became apparent that the provisions of this last extension would not be carried out an agreement between the Colombian Government and the New Panama Company was entered into on April 26, 1900, which extended the time of completion to October 31, 1910. The validity of this last extension of time has been questioned.

A new company, commonly known as the New Panama Canal Company, was organized on the 20th of October, 1894, with a capital stock of 650,000 shares of 100 francs each. Under the provisions of the agreement of December 26, 1890, authorizing an extension of time for the construction of the canal, 50,000 shares passed as full-paid stock to the Colombian Government, leaving the actual working capital of the New Panama Company at 60,000,000 francs, that amount having been subscribed in cash. The most of this capital stock was subscribed for by certain loan associations, administrators, contractors, and others against whom suits had been brought in consequence of the financial difficulties of the old company, it having been charged in the scandals attending bankruptcy proceedings that they had profited illegally. Those suits were discontinued under agreements to subscribe by the parties interested to the capital stock of the new company. The sums thus obtained constituted more than two-thirds of the 60,000,000 francs remaining of the share capital of the new company after the Colombian Government received its 50,000 shares. The old company had raised by the sale of stock and bond not far from $246,000,000, and the number of persons holding the securities thus sold has been estimated at over 200,000.

The Panama Railroad Company holds a concession from the Colombian Government giving it rights prior to those of the Wyse concession, so that the latter could not become effective without the concurrence of the Panama Railroad Company. This is shown by the language of Article III of the Wyse concession, which reads as follows:

"If the line of the canal to be constructed from sea to sea should pass to the west and to the north of the imaginary straight line which joins Cape Tiburon with Garachine Point, the grantees must enter into some amicable arrangement with the Panama Railroad Company or pay an indemnity, which shall be established in accordance with the

provisions of law 46, of August 16, 1867, 'approving the contract celebration on July 5, 1867, reformatory of the contract of April 15, 1850, for the construction of an iron railroad from one ocean to the other through the Isthmus of Panama.'" It became necessary, therefore, in order to control this feature of the situation, for the old Panama Company to secure at least a majority of the stock of the Panama Railroad Company. As a matter of fact the old Panama Canal Company purchased nearly 69,000 out of the 70,000 shares of the Panama Railroad Company, each such share having a par value of $100. These shares of Panama Railroad stock are now held in trust for the benefit of the New Panama Canal Company. A part of the expenditures of the old company therefore covered the cost of the Panama Railroad Company's shares now held in trust for the benefit of the new company.

Immediately after its organization the New Panama Canal Company resumed the work of excavation in the Emperador and Culebra cuts with a force of men which has been reported as varying between 1,900 and 3,600. It also gave thorough consideration to the subject of the best plan for the completion of the canal. The company's charter provided for the appointment of a special engineering commission of five members by the company and the liquidator to report upon the work done and the conclusions to be drawn from its study. This report was to be rendered when the amount expended by the new company should reach about one-half of its capital. At the same time the company also appointed a "Comité Technique," constituted of 14 eminent European and American engineers, to make a study of the entire project, which was to avail itself of existing data and the results of such other additional surveys and examinations as it might consider necessary. The report rendered by this committee was elaborate, and it was made November 16, 1898. It was referred to the statutory commission of five, to which reference has already been made, which commission reported in 1899 that the canal could be constructed within the limits of time and money estimated. On December 30, 1899, a special meeting of the stockholders of the new company was called, but the liquidator, who was one of the largest stockholders, declined to take part in it, and the report consequently has not received the required statutory consideration.

The plan adopted by the company placed the minimum elevation of the summit level of the canal at 97½ feet above the sea, and a maximum at 102½ feet above the same datum. It provided for a depth of 29½ feet of water and a bottom width of canal prism of about 98 feet, except at special places where this width was increased. A dam was to be built near Bohio, which would thus form an artificial lake, with its surface varying from 52.5 to 65.6 feet above the sea. Under this plan there would be a flight of two locks at Bohio, about 16 miles

from the Atlantic end of the canal, and another flight of two locks at Obispo, about 14 miles from Bohio, thus reaching the summit level; a single lock at Paraiso, between 6 and 7 miles from Obispo; a flight of two locks at Pedro Miguel, about 1.25 miles from Paraiso, and finally a single lock at Miraflores, a mile and a quarter from Pedro Miguel, bringing the canal down to the ocean elevation. The location of this line was practically the same as that of the old company. The available length of each lock chamber was 738 feet, while the available width was 82 feet, the depth in the clear being 32 feet 10 inches. The lifts were to vary from 26 to 33 feet. It was estimated that the cost of finishing the canal on this plan would be $101,850,000, exclusive of administration and financing.

In order to control the floods of the Chagres River, and to furnish a supply of water for the summit level of the canal, a dam was planned to be built at a point called Alhajuela, about 12 miles from Obispo, from which a feeder about 10 miles long, partly an open canal and partly in tunnels or pipe, would conduct the water from the reservoir thus formed to the summit level.

Although the plan as described was adopted, the "Comité Technique" apparently favored a modification by which a much deeper excavation through Culebra Hill would be made, thus omitting the locks at both Obispo and Paraiso and making the level of the artificial Lake Bohio the summit level of the canal. In this modified plan the bottom of the summit level would be about 32 feet above the sea, and the minimum elevation of the summit level 61.5 feet above the sea. This modification of plan had the material advantage of eliminating both the Obispo and Paraiso locks. The total estimated cost of completing the canal under this plan was about $105,500,000. Although the Alhajuela feeder would be omitted, the Alhajuela reservoir would be retained as an agent for controlling the Chagres floods and to form a reserve water supply. The difference in cost of these two plans was comparatively small, but the additional time required to complete that with the lower summit level was probably one of the main considerations in its rejection by the committee having it under consideration.

This brings the project up to the time when the Isthmian Canal Commission was created in 1899 and when the forces of the New Panama Canal Company were employed either in taking care of the enormous amount of plant bequeathed to it by the old company or in the great excavation at Emperador and Culebra. The total excavation of all classes, made up to the time when that Commission rendered its report, amounted to about 77,000,000 cubic yards.

The work of the Commission consisted of a comprehensive and detailed examination of the entire project and all its accessories, as contemplated by the New Panama Canal Company, and any modifica-

tions of its plans, either as to alignment, elevations, or subsidiary works, which it might determine advisable to recommend. In the execution of this work it was necessary, among other things, to send engineering parties on the line of the Panama route for the purpose of making surveys and examinations necessary to confirm estimates of the New Panama Canal Company as to quantities, elevations, or other physical features of the line selected, or required in modifications of alignment or plans. In order to accomplish this portion of its work the Commission placed five working parties on the Panama route with 20 engineers and other assistants and 41 laborers.

The Commission adopted for the purposes of its plans and estimates the route selected by the New Panama Canal Company, which is essentially that of the old company. Starting from the 6-fathom contour in the harbor of Colon the line follows the low marshy ground adjoining the Bay of Limon to its intersection with the Mindi River; thence through the low ground continuing to Gatun, about 6 miles from Colon, where it first meets the Chagres River. From this point to Obispo the canal line follows practically the general course of the Chagres River, although at one point in the marshes below Bohio it is nearly 2 miles from the farthest bend in the river, at a small place called Ahorca Lagarto. Bohio is about 17 miles from the Atlantic terminus, and Obispo about 30 miles. At the latter point the course of the Chagres River, passing upstream, lies to the northeast, while the general direction of the canal line is southeast toward Panama, the latter leaving the former at this location. The canal route follows up the general course of a small stream, called the Camacho, for a distance of nearly 5 miles, where the continental divide is found and in which the great Culebra cut is located, about 36 miles from Colon and 13 miles from the Panama terminus. After passing through the Culebra cut the canal route follows the course of the Rio Grande River to its mouth at Panama Bay. The mouth of the Rio Grande, where the canal line is located, is about a mile and a half westerly of the city of Panama. The Rio Grande is a small, sluggish stream throughout the last 6 miles of its course, and for that distance the canal excavation would be made mostly in soft silt or mud.

Although the line selected by the French company is that adopted by the Isthmian Canal Company for its purposes, a number of most important features of the general plan have been materially modified by the Commission, as will be easily understood from what has already been stated in connection with the French plans.

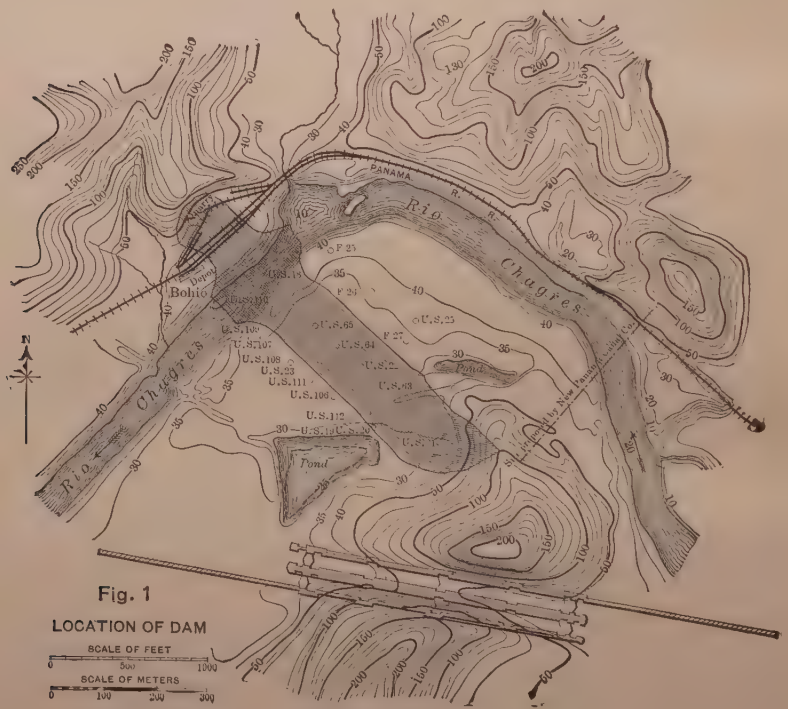
The feasibility of a sea-level canal, but with a tidal lock at the Panama end, was carefully considered by the Commission, and an approximate estimate of the cost of completing the work on that plan was made. In round numbers this estimated cost was about $250,000,000, and the time required to complete the work would

probably be nearly or quite twice that needed for the construction of a canal with locks. The Commission therefore adopted a project for the canal with locks. Both plans and estimates were carefully developed in accordance therewith.

The harbor of Colon has been fairly satisfactory for the commerce of that port, but it is open to the north, and there are probably two or three days in every year during which northers blow into the harbor with such intensity that ships anchored there must put to sea in order to escape damage. The western limit of this harbor is an artificial point of land formed by material deposited by the old Panama Canal Company; it is called Christoph Colon, and near its extreme end are two large frame residences built for De Lesseps. The entrance to the canal is immediately south of this artificial point. The Commission projected a canal entrance from the 6-fathom contour in the Bay of Limon, in which the harbor of Colon is found, swinging on a gentle curve, 6,560 feet radius, to the left around behind the artificial point just mentioned and then across the shore line to the right into the lowland southerly of Colon. This channel has a width of 500 feet at the bottom, with side slopes of 1 on 3, except on the second curve, which is somewhat sharper than the first, where the bottom width is made 800 feet for a length of 800 feet for the purpose of a turning-basin. This brings the line into the canal proper, forming a well-protected harbor for nearly a mile inside of the shore line. The distance from the 6-fathom line to this interior harbor is about 2 miles. The total cost of constructing the channel into the harbor and the harbor itself is $8,057,707, and the annual cost of maintenance is placed at $30,000. The harbor would be perfectly protected from the northers which occasionally blow with such intensity in the Bay of Limon, and it could readily be made in all weathers by vessels seeking it.

The harbor at the Pacific end of the channel where it joins Panama Bay is of an entirely different character in some respects. The Bay of Panama is a place of light winds. Indeed it has been asserted that the difficulties sometimes experienced by sailing vessels in finding wind enough to take them out of Panama Bay are so serious as to constitute a material objection to the location for a ship canal on the Panama route. This difficulty undoubtedly exists at times, but the simple fact is to be remembered that Panama was a port for sailing-ships for more than two hundred years before a steamship was known. The harbor of Panama, as it now exists, is a large area of water at the extreme northern limit of the bay, immediately adjacent to the city of Panama, protected from the south by the three islands of Perico, Naos, and Culebra. It has been called a roadstead. There is good anchorage for heavy-draft ships, but for the most part the water

is shallow. With the Commission's requirement of a minimum depth of water of 35 feet, a channel about 4 miles long from the mouth of the Rio Grande to the 6-fathom line in Panama Bay must be excavated. This channel would have a bottom width of 200 feet with side slopes of 1 on 3 where the material is soft. Considerable rock would have to be excavated in this channel. At 4.41 miles from the 6-fathom line is located a wharf at the point called La Boca. A branch of the Panama Railroad Company runs to this wharf, and at the present time deep-draft ships lie up alongside of it to take on and discharge cargo. The wharf is a steel frame structure, founded upon steel cylinders,



The Bohio dam site.

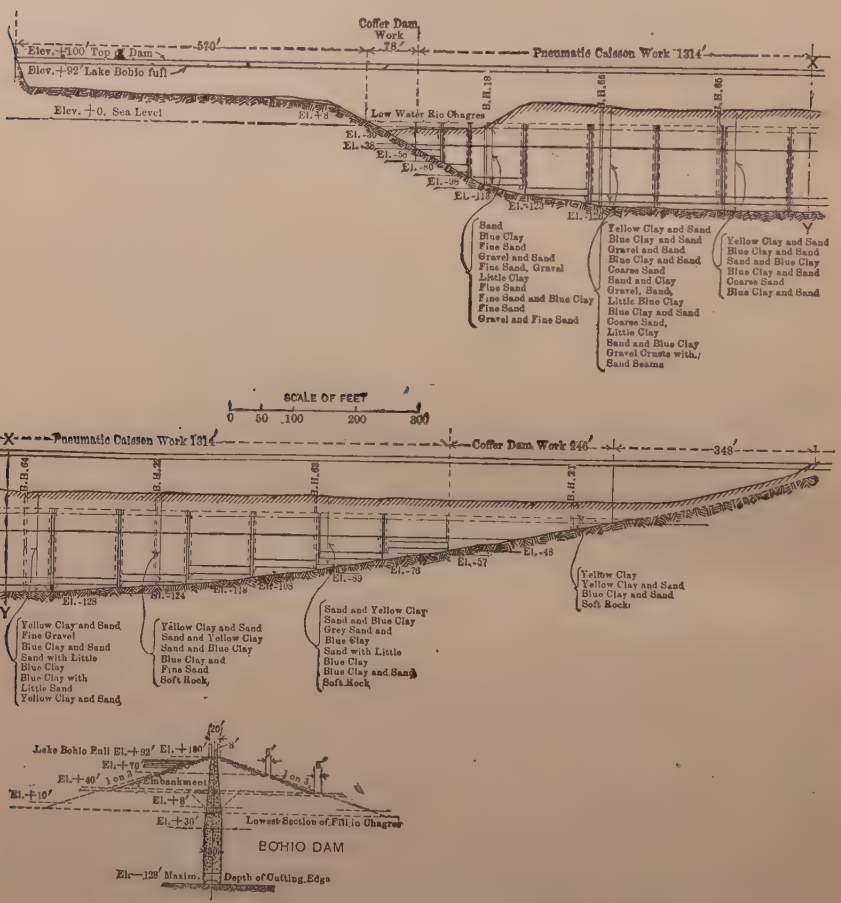
carried down to bed rock by the pneumatic process. Its cost was about $1,284,000. The total cost of the excavated channel leading from Panama Harbor to the pier at La Boca is estimated by the Commission at $1,464,513. As the harbor at Panama is considered an open roadstead, it requires no estimate for annual cost of maintenance.

Starting from the harbor of Colon, the prism of the canal is excavated through the low and for the most part marshy ground to the little village called Bohio. The prism would cut the Chagres River at a number of points, and would require a diversion channel for that river for a distance of about 5 miles on the westerly side of the canal.

Levees, or protective embankments, would also be required on the same side of the canal between Bohio and Gatun, the Chagres River leaving the canal line at the latter point on its way to the sea.

The principal engineering feature of the entire route is found at Bohio; it is the great dam across the Chagres River at that Point, forming Lake Bohio, the summit level of the canal. The new Panama Canal Company located this dam at a point about 17 miles from Colon, and designed to make it an earth structure suitably paved on its faces, but without any other masonry feature. Some borings had been made along the site, and test pits were also dug by the French engineers. It was the conviction of the Isthmian Canal Commission, however, that the character of the proposed dam might be affected by a further examination of the subsurface material at the site. Consequently the boring parties of the Commission sunk a large number of bore holes at six different sections or possible sites along the river in the vicinity of the French location. These borings revealed great irregularity in the character and disposition of the material below the bed and banks of the river. In some places the upper stratum of material was almost clear clay, and in other places clear sand, while all degrees of admixture of clay and sand were also found. At the French site the bed rock at the deepest point is 143 feet below sea level, with large masses of pervious and semipervious sand, gravel, and mixtures of those materials with clay. Apparently there is a geological valley in the rock along the general course of the Chagres River in this vicinity filled with sand, gravel, and clay, irregularly distributed and with all degrees of admixture, large masses in all cases being of open texture and pervious to water. The site adopted by the Commission for the purposes of its plans and estimates is located nearly half a mile down the course of the river from that selected by the New Panama Canal Company. The geological valley is nearly 2,000 feet wide at this location, but the deepest rock disclosed by the borings of the Commission is but 128 feet below sea level. The actual channel of the river is not more than 150 feet wide and lies on the extreme easterly side of the valley. The easterly or right bank of the river at this place is clean rock and rises abruptly to an elevation of about 40 feet above the river surface at ordinary stages. The left or westerly bank of the river is compacted clay and sand, and rises equally as abruptly as the rocky bank of the other side, and to about the same elevation. From the top of the abrupt sandy clay bank a plateau of rather remarkable uniformity of elevation extends for about 1,200 feet in a southwesterly direction to the rocky hill in which the Bohio locks would be located. The rock slope on the easterly or northerly bank of the river runs down under the sandy river bed, but at such an inclination that within the limits of the channel the deepest rock is less than 100 feet below sea level.

After the completion of all its examinations, and after a careful study of the data disclosed by them, the Commission deemed it advisable to plan such a dam as would cut off absolutely all possible subsurface flow or seepage through the sand and gravel below the river surface. It is to be observed that such a subsurface flow might either disturb the stability of an earth dam or endanger the water supply of the summit level of the canal, or both. The plan of dam finally



Profile of Bohio dam site, selected for plans and estimate, with section of dam.

adopted by the Commission for the purposes of its estimates is shown by the accompanying plans and sections. A heavy core wall of concrete masonry extends from bed rock across the entire geological valley to the top of the structure, or to an elevation of 100 feet above sea level, thus absolutely closing the entire valley against any possible flow. The thickness of this wall at the bottom is 30 feet, but at an elevation of 30 feet below sea level its sides begin to batter at such a

rate as to make the thickness of the wall 8 feet at its top. On either side of this wall are heavy masses of earth embankment of selected material properly deposited in layers with surface slopes of 1 on 3. As shown by the plans, the lower portions of the core wall of this dam would be sunk to bed rock by the pneumatic process, the joints between the caissons being closed and sealed by cylinders sunk in recesses or wells, also as shown by the plans.

The profile of this route shows that the summit level would have an ordinary elevation of 85 feet above the sea, but it may be drawn down for uses of the canal to a minimum elevation of 82 feet above the same datum. On the other hand, under circumstances to be discussed later, it may rise during the floods of the Chagres to an elevation of 90 or possibly 91 or 92 feet above the level of the sea. The top of the dam, therefore, would be from 8 to 10 feet above the highest possible water surface in the lake, which is sufficient to guard against wash or overtopping of the dam by waves. The total width of the dam at its top would be 20 feet, and the entire inner slope would be paved with heavy riprap suitably placed and bedded.

This dam would create an artificial lake having a superficial area during high water of about 40 square miles. The water would be backed up to a point called Alhajuela, about 25 miles up the river from Bohio. For a distance of nearly 14 miles—i. e., from Bohio to Obispo—the route of the canal would lie in this lake. Although the water would be from 80 to 90 feet deep at the dam for several miles below Obispo, it would be necessary to make some excavation along the general course of the Chagres in order to secure the minimum depth of 35 feet for the navigable channel.

The feature of Lake Bohio of the greatest importance to the safe and convenient operation of the canal is that by which the floods of the river Chagres are controlled or regulated. That river is but little less than 150 miles long, and its drainage area, as nearly as can be estimated, contains about 875 square miles. Above Bohio its current moves some sand and a little silt in times of flood, but usually it is a clear-water stream. In low water its discharge may fall to 350 cubic feet per second.

As is well known, the floods of the Chagres have at times been regarded as almost, if not quite, insurmountable obstacles to the construction of a canal on this line. The greatest flood of which there is any semblance of a reliable record is one which occurred in 1879. No direct measurements were made, but it is stated, with apparent authority, that the flood elevation at Bohio was 39.3 feet above low water. If the total channel through which the flood flowed at that time had been as large as at present, actual gaugings or measurements of subsequent floods show that the maximum discharge in 1879 might have been at the rate of 136,000 cubic feet per second. As a matter

of fact, the total channel section in that year was less than it is at the present time. Hence, if it be assumed that a flood of 140,000 cubic feet per second must be controlled, an error on the safe side will be committed. Other great floods of which there are reliable records are as follows:

Year.	Height at Bohio above low water.
	Feet.
1885	33.8
1888	34.7
1890	32.1
1893	28.5

The maximum measured rate of the 1890 flood was 74,998 cubic feet per second, and that of 1893, 48,975 cubic feet per second. It is clear, therefore, that a flood flow of 75,000 cubic feet per second is very rare, and that a flood of 140,000 cubic feet per second exceeds that of which we have any record for practically forty years.

It is obvious that the dam, as designed by the Commission, is of such character that no water must be permitted to flow over its crest or even in immediate proximity to the downstream embankment. Indeed, it is not intended by the Commission that there shall be any wasteway or discharge anywhere near the dam. At a point about 3 miles southwest of the site of the dam at Bohio is a low saddle or notch in the hills, near the head waters of a small stream called the Gigante River. The elevation of this saddle or notch is such that a solid masonry weir, with a crest 2,000 feet long, may readily be constructed with its foundations on bed rock without deep excavation. This structure is called the Gigante spillway, and all surplus flood waters from the Chagres would flow over it. The waters discharged would flow down to and through some large marshes, one called Peña Blanca and another Agua Clara, before rejoining the Chagres. Inasmuch as the canal line runs just easterly of those marshes, it would be necessary to protect it with the levees or embankments to which allusion has already been made. These embankments are neither much extended nor very costly for such a project. The protection of the canal would be further aided by a short artificial channel between the two marshes, Peña Blanca and Agua Clara, for which provision is made in the estimates of the Commission. After the surplus waters from the Gigante spillway pass these marshes they again enter the Chagres River or flow over the low, half-submerged country along its borders, and thence through its mouth to the sea near the town of Chagres, about 6 miles northwest of Gatun.

The masonry crest of the Gigante spillway would be placed at an elevation of 85 feet above the sea, identically the same as that which may be called the normal summit level of the canal. It is estimated

that the total uses of water in the canal added to the loss by evaporation, taken at 6 inches in depth per month, from the surface of the lake will amount to about 1,070 cubic feet per second if the traffic through the canal should amount to 10,000,000 tons per annum in ships of ordinary size. This draft per second is the sum of 406 cubic feet per second for lockage, 207 for evaporation, 250 for leakage at lock gates, and 200 for power and other purposes, making a total of 1,063, which has been taken as 1,070 cubic feet per second. The amount of storage in Lake Bohio between the elevations of 85 and 82 feet above sea level, as designed, is sufficient to supply the needs of that traffic in excess of the smallest recorded low-water flow of the Chagres River during the dry season of a low-rainfall year. The lowest monthly average flow of the Chagres on record at Bohio is 600 cubic feet per second for March, 1891, and for the purposes of this computation that minimum flow has been supposed to continue for three months. This includes a sensible margin of safety. In not even the driest year, therefore, can it be reasonably expected that the summit level of the canal would fall below the elevation of 82 feet until the total traffic of the canal carried in ships of the present ordinary size shall exceed 10,000,000 tons. If the average size of ships continues to increase, as will probably be the case, less water in proportion to tonnage will be required for the purposes of lockage. This follows from the fact that with a given tonnage the greater the capacity of the ships the less the number required, and consequently the less will be the number of lockages made.

On the other hand it can be shown that with a depth of 5 feet of water on the crest of the Gigante spillway the discharge of that weir 2,000 feet long will be at the rate of 78,260 cubic feet per second. If the flood waters of the Chagres should flow into Lake Bohio until the head of water on the crest of the Gigante weir rises to 7½ feet, the rate of discharge over that weir would be 140,000 cubic feet per second, which, as already shown, exceeds at least by a little the highest flood rate on record. The operation of Lake Bohio as a flood controller or regulator is therefore exceedingly simple. The flood waters of the Chagres would pour into the lake and immediately begin to flow over the Gigante weir, and continue to do so at an increasing rate as the flood continues. The discharge of the weir is augmented by the increasing flood, and decreases only after the passage of the crest of the flood wave. No flood even as great as the greatest supposable flood on record can increase the elevation of the lake more than 92 to 92½ feet above sea level, and it will only be at long intervals of time when floods will raise that elevation more than about 90 feet above sea level. The control is automatic and unfailingly certain. It prevents absolutely any damage from the highest supposable floods of the Chagres, and reserves in Lake Bohio all that is required for the

purposes of the canal and for wastage by evaporation through the lowest rainfall season. The floods of the Chagres, therefore, instead of constituting the obstacle to construction and convenient maintenance of the canal heretofore supposed, are deprived of all their prejudical effects and transformed into beneficial agents for the operation of the waterway.

The highest floods are of short duration, and it can be stated as a general law that the higher the flood the shorter its duration. The great floods which it is necessary to consider in connection with the maintenance and operation of this canal would last but a comparatively few hours only. The great flood flow of 140,000 cubic feet per second would increase the current in the narrowest part of the canal below Obispo to possibly 5 feet per second for a few hours only, but that is the only inconvenience which would result from such a flood discharge. That velocity could be reduced by additional excavation.

Inasmuch as this system of control, devised and adopted by the Isthmian Canal Commission, is completely effective in regulating the Chagres floods, the reservoir proposed to be constructed by the new Panama Canal Company at Alhajuela, on the Chagres about 11 miles above Obispo, is not required, and the cost of its construction would be avoided. It could, however, as a project, be held in reserve. If the traffic of the canal should increase to such an extent that more water would be needed for feeding the summit level, the dam could be built at Alhajuela so as to impound enough additional water to accommodate, with that stored in Lake Bohio, at least five times the 10,000,000 annual traffic already considered. Its existence would at the same time act with substantial effect in controlling the Chagres floods and relieve the Gigante spillway of a corresponding amount of duty.

The locks on the Panama route are designed to have * * * a usable length of 740 feet and a clear width of 84 feet. They would be built chiefly of concrete masonry, while the gates would be of steel and of the miter type.

The great dam at Bohio raises the water surface in the canal from sea level in the Atlantic maritime section to an ordinary maximum of 90 feet above sea level; in other words, the maximum ordinary total lift would be 90 feet. This total lift is divided into two parts of 45 feet each. There is therefore a flight of two locks at Bohio; indeed, there are two flights side by side, as the twin arrangement is designed to be used at all lock sites on both routes. The typical dimensions and arrangements of these locks, with the requisite culverts and other features, * * * are not essentially different from other great modern ship-canal locks. The excavation for the Bohio locks is made in a rocky hill against which the southwesterly end of the proposed Bohio dam rests, and they are less than 1,000 feet from it.

After leaving Bohio Lake at Obispo a flight of two locks is found at Pedro Miguel, about 7.9 miles from the former or 21½ miles from Bohio. These locks have a total ordinary maximum lift of 60 feet, divided into two lifts of 30 feet each. The fifth and last lock on the route is at Miraflores. The average elevation of water between Pedro Miguel and Miraflores is 30 feet above mean sea level. Inasmuch as the range of tide between high and low in Panama Bay is about 20 feet, the maximum lift at Miraflores is 40 feet and the minimum about 20. The twin locks at Miraflores bring the canal surface down to the Pacific Ocean level, the distance from those locks to the 6-fathom curve in Panama Bay being 8.54 miles. There are therefore five locks on the Panama route, all arranged on the twin plan, and, as on the Nicaragua route, all are founded on rock.

Near Obispo a pair of guard gates are arranged "so that if it should become necessary to draw off the water from the summit cut the level of Lake Bohio would not be affected."

An unprecedented concentration of heavy cutting is found between Obispo and Pedro Miguel. This is practically one cut, although the northwesterly end toward Obispo is called the Emperador, while the deepest part at the other end, about 3 miles from Pedro Miguel, is the great Culebra cut, with a maximum depth on the center line of the canal of 286 feet. On page 93 of the Isthmian Canal Commission's report is the following reference to the material in this cut: "There is a little very hard rock at the eastern end of this section, and the western 2 miles are in ordinary materials. The remainder consists of a hard indurated clay, with some softer material at the top and some strata and dikes of hard rock. In fixing the price it has been rated as soft rock, but it must be given slopes equivalent to those in earth. This cut has been estimated on the basis of a bottom width of 150 feet, with side slopes of 1 on 1." When the old Panama Canal Company began its excavation in this cut considerable difficulty was experienced by the slipping of the material outside of the limits of the cut into the excavation, and the marks of that action can be seen plainly at the present time. This experience has given an impression that much of the material in this cut is unstable, but that impression is erroneous. The clay which slipped in the early days of the work was not drained, and, like wet clay in numerous places in this country, it slipped down into the excavation. This material is now drained and is perfectly stable. There is no reason to anticipate any future difficulty if reasonable conditions of drainage are maintained. The high faces of the cut will probably weather to some extent, although experience with such clay faces on the isthmus indicates that the amount of such action will be small. As a matter of fact, the material in which the Culebra cut is made is stable, and will give no sensible difficulty in maintenance.

Throughout the most of the distance between Colon and Bohio on

the easterly side of the canal the French plan contemplated an excavated channel to receive a portion of the waters of the Chagres as well as the flow of two smaller rivers the Gatuncillo and the Mindi —so as to conduct them into the Bay of Manzanillo, immediately to the east of Colon. That so-called diversion channel was nearly completed. Under the plan of the Commission it would receive none of the Chagres flow, but it would be available for intercepting the drainage of the high ground easterly of the canal line and the flow of the two small rivers named, so that these waters would not find their way into the canal. There are a few other small works of similar character in different portions of the line, all of which were recognized and provided for by the Commission.

The total length of the Panama route from the 6-fathom curve at Colon to the same curve in Panama Bay is 49.09 miles. The general direction of the route in passing from Colon to Panama is from northwest to southeast, the latter point being about 22 miles east of the Atlantic terminus. The depression through which the line is laid is one of easy topography, except at the continental divide in the Culebra cut. As a consequence, there is little heavy work of excavation, as such matters go, except in that cut. A further consequence of such topography is a comparatively easy alignment; that is, one in which the amount of curvature is not high. The smallest radius of curvature is 3,281 feet at the entrance to the inner harbor at the Colon end of the route, and where the width is 800 feet. The radii of the remaining curves range from 6,234 feet to 19,629 feet.

The following table gives all the elements of curvature on the route and indicates that it is not excessive:

Number of curves.	Length.	Radius.	Total curvature.
	Miles.	*Feet.*	° ′
1	0.88	19,629	14 17
1	.48	13,123	11 04
4	4.22	11,483	111 32
15	11.61	9,842	355 50
4	2.44	8,202	90 20
2	1.67	6,562	77 00
1	.73	6,234	35 45
1	.82	3,281	75 51
	22.85		771 39

The principal items of the total amount of work to be performed in completing the Panama Canal, under the plan of the Commission, can be classified as shown in the following table:

Dredging	cubic yards	27,659,540
Dry earth	do	14,386,954
Soft rock	do	39,893,235
Hard rock	do	8,806,340
Rock under water	do	4,891,667
Embankment and back filling	do	1,802,753
Total	do	97,440,489

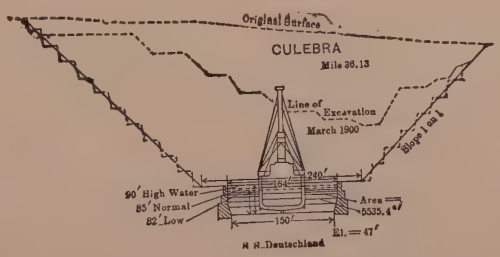
Concrete	cubic yards	3,762,175
Granite	do	13,820
Iron and steel	pounds	65,248,900
Excavation in cofferdam	cubic yards	7,260
Pneumatic work	do	108,410

The lengths of the various sections of this route and the costs of completing the work upon them are fully set forth in the following table, taken from the Commission's report, as were the two preceding:

Total estimated cost.

	Miles.	Cost.
Colon entrance and harbor	2.39	$8,057,707
Harbor to Bohio locks, including levees	14.42	11,099,839
Bohio locks, including excavation	.35	11,567,275
Lake Bohio	13.61	2,952,154
Obispo gates		295,434
Culebra section	7.91	44,414,460
Pedro Miguel locks, including excavation and dam	.35	9,081,321
Pedro Miguel level	1.33	1,192,286
Miraflores locks, including excavation and spillway	.20	5,781,401
Pacific level	8.53	12,427,971
Bohio dam		6,369,640
Gigante spillway		1,209,419
Peña Blanca outlet		2,448,076
Chagres diversion		1,929,982
Gatun diversion		100,000
Panama Railroad diversion		1,267,500
Total	49.09	120,194,465
Engineering, police, sanitation, and general contingencies, 20 per cent		24,038,893
Aggregate		144,233,358

The item in this table called Panama Railroad diversion affords provision for the reconstruction of the railroad necessitated by the formation of Lake Bohio. That lake would submerge the present location of the railroad for 14 or 15 miles. * * *



The Culebra cut with steamer *Deutschland* in it.

As is well known, the entire Central American isthmus is a volcanic region, and in the past a considerable number of destructive volcanic eruptions have taken place at a number of points. There is a line of live volcanoes extending southeasterly through Nicaragua and Costa Rica. Many earthquake shocks have occurred throughout Nicaragua, Costa Rica, and the State of Panama, some of which have done more or less damage in large portions of those districts. * * * The

conclusions of the Commission as to this feature of the matter are concisely stated in the following paragraphs of its report:

"It is possible and even probable that the more accurately fitting portions of the canal, such as the lock gates, may at times be distorted by earthquakes, and some inconvenience may result therefrom. That contingency may be classed with the accidental collision of ships with the gates, and is to be provided for in the same way, by duplicate gates.

"It is possible also that a fissure might open which would drain the canal, and, if it remained open, might destroy it. This possibility should not be erected by the fancy into a threatening danger. If a timorous imagination is to be the guide, no great work can be undertaken anywhere. This risk may be classed with that of a great conflagration in a city, like that of Chicago in 1871, or Boston in 1872.

"It is the opinion of the Commission that such danger as exists from earthquakes is essentially the same for both the Nicaragua and Panama routes, and that in neither case is it sufficient to prevent the construction of the canal."

The Nicaragua route crosses the line of live volcanoes running from northwest to southeast through Central America, and the crater of Ometepe in Lake Nicaragua is about 11 miles only from the line. The eruptions of Pelée and Soufrière show that such proximity of possible volcanic action may be a source of great danger, although even the destruction by them does not certainly indicate damage either to navigation or to canal structures at the distance of 11 miles. Whatever volcanic danger may exist lies on the Nicaragua route, for there is no volcano nearer than 175 miles to the Panama route.

* * * There is a wide-spread, popular impression that the Central American countries are necessarily intensely unhealthful. This is an error, in spite of the facts that the construction of the Panama Railroad was attended with an appalling amount of sickness and loss of life, and that records of many epidemics at other times and in other places exist in nearly all of these countries. There are the best of good reasons to believe that with the enforcement of sanitary regulations, which are now well understood and completely available, the Central American countries would be as healthful as our Southern States. A proper recognition of hygienic conditions of life suitable to a tropical climate would work wonders in Central America in reducing the death rate. At the present time the domestic administration of most of the cities and towns of Nicaragua and Panama, as well as the generality of Central American cities, is characterized by the absence of practically everything which makes for public health, and by the presence of nearly every agency working for the diseases which flourish in tropical climates. When the United States Government reaches the point of actual construction of an isthmian canal the sanitary features of that work should be administered and enforced in every detail with the rigor of the most exacting military discipline.

Under such conditions, epidemics could either be avoided or reduced to manageable dimensions, but not otherwise. * * *

The time required for passing through a transisthmian canal is affected by the length, by the number of locks, by the number of curves, and by the sharpness of curvature. The speed of a ship, and consequently the time of passage, is also affected by the depth of water under its keel. It is well known that the same power applied to a ship in deep water of unlimited width will produce a much higher rate of movement than the same power applied to the same ship in a restricted waterway, especially when the draft of the ship is but little less than the depth of water. These considerations have important bearings both upon the dimensions of a ship canal and upon the time required to pass through it. They were most carefully considered by the Commission, as were also such other matters as the delay incurred in passing through the locks on each line, the latter including the delay of slowing or approaching the lock and of increasing speed after passing it, the time of opening and closing the gates, and the time of emptying and filling the locks. It is also evident that ships of various sizes will require different times for their passage. After giving due weight to all these considerations it was found that what may be called an average ship would require twelve hours for passing through the Panama Canal. * * *

The prospective industrial and commercial value of the canal also occupied the attention of the Commission in a broad and careful study of the elements which enter that part of the problem. It is difficult if not impossible to predict just what the effect of a transisthmian canal would be either upon the ocean commerce of the United States or of other parts of the world, but it seems reasonable to suppose from the result of the Commission's examinations that had the canal been in existence in 1899 at least 5,000,000 tons of the actual traffic of that year would have been accommodated by it. The opening of such a waterway, like the opening of all other traffic routes, induces the creation of new traffic to an extent that can not be estimated, but it would appear to be reasonable to suppose that within ten years from the date of its opening the vessel tonnage using it would not be less than 10,000,000 tons. * * *

The effect of this ship waterway upon the well-being of the United States is not altogether of a commercial character. As indicated by the Commission, this additional bond between the two portions of the country will have a beneficial effect upon the unity of the political interests as well as upon the commercial welfare of the country. Indeed it is the judgment of many well-informed people that the commercial advantages resulting from a closer touch between the Atlantic and Pacific coasts of the country are of less consequence than the unifying of political interests.

THE PROBLEMS OF HEREDITY AND THEIR SOLUTION.[a]

By W. Bateson, M. A., F. R. S.[b]

An exact determination of the laws of heredity will probably work more change in man's outlook on the world and in his power over nature than any other advance in natural knowledge that can be clearly foreseen.

There is no doubt whatever that these laws can be determined. In comparison with the labor that has been needed for other great discoveries we may even expect that the necessary effort will be small. It is rather remarkable that while in other branches of physiology such great progress has of late been made, our knowledge of the phenomena of heredity has increased but little; though that these phenomena constitute the basis of all evolutionary science and the very central problem of natural history is admitted by all. Nor is this due to the special difficulty of such inquiries so much as to general neglect of the subject.

It is in the hope of inducing others to follow these lines of investigation that I take the problems of heredity as the subject of this lecture to the Royal Horticultural Society.

No one has better opportunities of pursuing such work than horticulturists and stock breeders. They are daily witnesses of the phenomena of heredity. Their success also depends largely on a knowledge of its laws, and obviously every increase in that knowledge is of direct and special importance to them.

The want of systematic study of heredity is due chiefly to misapprehension. It is supposed that such work requires a lifetime. But though for adequate study of the complex phenomena of inheritance long periods of time must be necessary, yet in our present state of

[a] Reprinted by permission of the author and the publisher from Mendel's Principles of Heredity, a Defense by W. Bateson, M. A., F. R. S., with a translation of Mendel's original papers on hybridisation, Cambridge [England]: At the University Press, 1902.

[b] The first half of this paper is reprinted, with additions and modifications, from the Journal of the Royal Horticultural Society, 1900, Vol. XXV, parts 1 and 2. Written almost immediately after the rediscovery of Mendel, it will be seen to be already in some measure out of date, but it may thus serve to show the relation of the new conceptions to the old. (Author's footnote to title on page 1 of the volume.)

deep ignorance almost of the outline of the facts, observations carefully planned and faithfully carried out for even a few years may produce results of great value. In fact, by far the most appreciable and definite additions to our knowledge of these matters have been thus obtained.

There is besides some misapprehension as to the kind of knowledge which is especially wanted at this time, and as to the modes by which we may expect to obtain it. The present paper is written in the hope that it may in some degree help to clear the ground of these difficulties by a preliminary consideration of the question, How far have we got toward an exact knowledge of heredity, and how can we get farther?

Now, this is preeminently a subject in which we must distinguish what we can do from what we want to do. We want to know the whole truth of the matter; we want to know the physical basis, the inward and essential nature, "the causes," as they are sometimes called, of heredity; but we want also to know the laws which the outward and visible phenomena obey.

Let us recognize from the outset that as to the essential nature of these phenomena we still know absolutely nothing. We have no glimmering of an idea as to what constitutes the essential process by which the likeness of the parent is transmitted to the offspring. We can study the processes of fertilization and development in the finest detail which the microscope manifests to us, and we may fairly say that we have now a considerable grasp of the visible phenomena; but of the nature of the physical basis of heredity we have no conception at all. No one has yet any suggestion, working hypothesis, or mental picture that has thus far helped in the slightest degree to penetrate beyond what we see. The process is as utterly mysterious to us as a flash of lightning is to a savage. We do not know what is the essential agent in the transmission of parental characters, not even whether it is a material agent or not. Not only is our ignorance complete, but no one has the remotest idea how to set to work on that part of the problem. We are in the state in which the students of physical science were in the period when it was open to anyone to believe that heat was a material substance or not, as he chose.

But apart from any conception of the essential modes of transmission of characters, we can study the outward facts of the transmission. Here, if our knowledge is still very vague, we are at least beginning to see how we ought to go to work. Formerly, naturalists were content with the collection of numbers of isolated instances of transmission—more especially, striking and peculiar cases—the sudden appearance of highly prepotent forms, and the like. We are now passing out of that stage. It is not that the interest of particular cases has in any way diminished—for such records will always have their value—

but it has become likely that general expressions will be found capable of sufficiently wide application to be justly called "laws" of heredity. That this is so was till recently due almost entirely to the work of Mr. F. Galton, to whom we are indebted for the first systematic attempt to enunciate such a law.

All laws of heredity so far propounded are of a statistical character and have been obtained by statistical methods. If we consider for a moment what is actually meant by a "law of heredity" we shall see at once why these investigations must follow statistical methods. For a "law" of heredity is simply an attempt to declare the course of heredity under given conditions. But if we attempt to predicate the course of heredity we have to deal with conditions and groups of causes wholly unknown to us, whose presence we can not recognize, and whose magnitude we can not estimate in any particular case. The course of heredity in particular cases therefore can not be foreseen.

Of the many factors which determine the degree to which a given character shall be present in a given individual only one is usually known to us, namely, the degree to which that character is present in the parents. It is common knowledge that there is not that close correspondence between parent and offspring which would result were this factor the only one operating; but that, on the contrary, the resemblance between the two is only an uncertain one.

In dealing with phenomena of this class the study of single instances reveals no regularity. It is only by collection of facts in great numbers, and by statistical treatment of the mass, that any order or law can be perceived. In the case of a chemical reaction, for instance, by suitable means the conditions can be accurately reproduced, so that in every individual case we can predict with certainty that the same result will occur. But with heredity it is somewhat as it is in the case of the rainfall. No one can say how much rain will fall to-morrow in a given place, but we can predict with moderate accuracy how much will fall next year, and for a period of years a prediction can be made which accords very closely with the truth.

Similar predictions can from statistical data be made as to the duration of life and a great variety of events, the conditioning causes of which are very imperfectly understood. It is predictions of this kind that the study of heredity is beginning to make possible, and in that sense laws of heredity can be perceived.

We are as far as ever from knowing why some characters are transmitted, while others are not; nor can anyone yet foretell which individual parent will transmit characters to the offspring and which will not; nevertheless the progress made is distinct.

As yet investigations of this kind have been made in only a few instances, the most notable being those of Galton on human stature

and on the transmission of colors in Basset hounds. In each of these cases he has shown that the expectation of inheritance is such that a simple arithmetical rule is approximately followed. The rule thus arrived at is that of the whole heritage of the offspring the two parents together, on an average, contribute one-half, the four grand parents one-fourth, the eight great grand parents one-eighth, and so on, the remainder being contributed by the remoter ancestors.

Such a law is obviously of practical importance. In any case to which it applies we ought thus to be able to predict the degree with which the purity of a strain may be increased by selection in each successive generation.

To take a perhaps impossibly crude example, if a seedling show any particular character which it is desired to fix, on the assumption that successive self-fertilizations are possible, according to Galton's law the expectation of purity should be in the first generation of self-fertilization 1 in 2, in the second generation 3 in 4, in the third 7 in 8, and so on.[a]

But already many cases are known to which the rule in any simple form will not apply. Galton points out that it takes no account of individual prepotencies. There are, besides, numerous cases in which on crossing two varieties the character of one variety almost always appears in each member of the first crossbred generation. Examples of these will be familiar to those who have experience in such matters. The offspring of the Polled Angus cow and the Shorthorn bull is almost invariably polled or with very small loose "scurs." Seedlings raised by crossing *Atropa belladonna* with the yellow-fruited variety have without exception the blackish-purple fruits of the type. In several hairy species, when a cross with a glabrous variety is made, the first crossbred generation is altogether hairy.[b]

Still more numerous are examples in which the characters of one variety very largely, though not exclusively, predominate in the offspring.

These large classes of exceptions—to go no further—indicate that, as we might in any case expect, the principle is not of universal application, and will need various modifications if it is to be extended to more complex cases of inheritance of varietal characters. No more useful work can be imagined than a systematic determination of the precise "law of heredity" in numbers of particular cases.

Until lately the work which Galton accomplished stood almost alone in this field, but quite recently remarkable additions to our knowledge of these questions have been made. In the year 1900, Professor de Vries

[a] See later. Galton gave a simple diagrammatic representation of his law in Nature, 1898, Vol. LVII, p. 293.

[b] These we now recognize as examples of Mendelian "dominance."

published a brief account[a] of experiments which he has for several years been carrying on, giving results of the highest value.

The description is very short, and there are several points as to which more precise information is necessary, both as to details of procedure and as to statement of results. Nevertheless, it is impossible to doubt that the work as a whole constitutes a marked step forward, and the full publication which is promised will be awaited with great interest.

The work relates to the course of heredity in cases where definite varieties differing from each other in some one definite character are crossed together. The cases are all examples of discontinuous variation—that is to say, cases in which actual intermediates between the parent forms are not usually produced on crossing.[b] It is shown that the subsequent posterity obtained by self-fertilizing these crossbreds or hybrids, or by breeding them with each other, break up into the original parent forms according to fixed numerical rule.

Professor de Vries begins by reference to a remarkable memoir by Gregor Mendel,[c] giving the results of his experiments in crossing varieties of *Pisum sativum*. These experiments of Mendel's were carried out on a large scale, his account of them is excellent and complete, and the principles which he was able to deduce from them will certainly play a conspicuous part in all future discussions of evolutionary problems. It is not a little remarkable that Mendel's work should have escaped notice and been so long forgotten.

For the purposes of his experiments Mendel selected seven pairs of characters, as follows:

1. Shape of ripe seed, whether round or angular and wrinkled.
2. Color of "endosperm" (cotyledons), whether some shade of yellow or a more or less intense green.
3. Color of the seed skin, whether various shades of gray and gray-brown or white.
4. Shape of seed pod, whether simply inflated or deeply constricted between the seeds.
5. Color of unripe pod, whether a shade of green or bright yellow.
6. Nature of inflorescence, whether the flowers are arranged along the axis of the plant or are terminal and form a kind of umbel.
7. Length of stem, whether about 6 or 7 feet long or about three-fourths to 1½ feet.

Large numbers of crosses were made between pease differing in respect of one of each of these pairs of characters. It was found that in each case the offspring of the cross exhibited the character of one of the parents in almost undiminished intensity, and intermediates which

[a] Comptes Rendus, March 26, 1900, and Ber. d. Deutsch. Bot. Ges., XVIII, 1900, p. 83.

[b] This conception of discontinuity is, of course, pre-Mendelian.

[c] "Versuche üb. Pflanzenhydriden" in the Verh. d. Naturf. Ver.·Brünn, IV, 1865.

could not be at once referred to one or other of the parental forms were not found.

In the case of each pair of characters there is thus one which in the first cross prevails to the exclusion of the other. This prevailing character Mendel calls the dominant character, the other being the recessive character.[a]

That the existence of such "dominant" and "recessive" characters is a frequent phenomenon in crossbreeding, is well known to all who have attended to these subjects.

By letting the crossbreds fertilize themselves Mendel next raised another generation. In this generation were individuals which showed the dominant character, but also individuals which presented the recessive character. Such a fact also was known in a good many instances. But Mendel discovered that in this generation the numerical proportion of dominants to recessives is on an average of cases approximately constant, being in fact as three to one. With very considerable regularity these numbers were approached in the case of each of his pairs of characters.

There are thus in the first generation raised from the crossbreds 75 per cent dominants and 25 per cent recessives.

These plants were again self-fertilized, and the offspring of each plant separately sown. It next appeared that the offspring of the recessives remained pure recessive, and in subsequent generations never produced the dominant again.

But when the seeds obtained by self-fertilizing the dominants were examined and sown it was found that the dominants were not all alike, but consisted of two classes, (1) those which gave rise to pure dominants, and (2) others which gave a mixed offspring, composed partly of recessives, partly of dominants. Here also it was found that the average numerical proportions were constant, those with pure dominant offspring being to those with mixed offspring as one to two. Hence it is seen that the 75 per cent dominants are not really of similar constitution, but consist of twenty-five which are pure dominants and fifty which are really crossbreds, though, like the crossbreds raised by crossing the two original varieties, they only exhibit the dominant character.

To resume, then, it was found that by self-fertilizing the original crossbreds the same proportion was always approached, namely, 25 dominants, 50 crossbreds, 25 recessives, or $1D : 2DR : 1R$.

Like the pure recessives, the pure dominants are thenceforth pure, and only give rise to dominants in all succeeding generations studied.

On the contrary the fifty crossbreds, as stated above, have mixed offspring. But these offspring, again, in their numerical proportions,

[a] Note that by these novel terms the complications involved by use of the expression "prepotent" are avoided.

follow the same law, namely, that there are three dominants to one recessive. The recessives are pure like those of the last generation, but the dominants can, by further self-fertilization, and examination or cultivation of the seeds produced, be again shown to be made up of pure dominants and crossbreds in the same proportion of one dominant to two crossbreds.

The process of breaking up into the parent forms is thus continued in each successive generation, the same numerical law being followed so far as has yet been observed.

Mendel made further experiments with *Pisum sativum*, crossing pairs of varieties which differed from each other in two characters, and the results, though necessarily much more complex, showed that the law exhibited in the simpler case of pairs differing in respect of one character operated here also.

In the case of the union of varieties AB and ab differing in two distinct pairs of characters, A and a, B and b, of which A and B are dominant, a and b recessive, Mendel found that in the first crossbred generation there was only one class of offspring, really $AaBb$.

But by reason of the dominance of one character of each pair these first crosses were hardly, if at all, distinguishable from AB.

By letting these $AaBb$'s fertilize themselves, only four classes of offspring seemed to be produced, namely,

AB showing both dominant characters.
Ab showing dominant A and recessive b.
aB showing recessive a and dominant B.
ab showing both recessive characters a and b.

The numerical proportions in which these classes appeared were also regular and approached the ratio

$$9AB : 3\,Ab : 3aB : 1ab.$$

But on cultivating these plants and allowing them to fertilize themselves it was found that the members of the

Ratios		
1		ab class produce only ab's.
3	1	aB class may produce either all aB's,
	2	*or* both aB's and ab's.
3	1	Ab class may produce either all Ab's,
	2	*or* both Ab's and ab's.
9	1	AB class may produce either all AB's,
	2	*or* both AB's and Ab's,
	2	*or* both AB's and aB's,
	4	*or* all four possible classes again, namely, AB's, Ab's, aB's, and ab's,

and the average number of members of each class will approach the ratio 1 : 3 : 3 : 9 as indicated above.

The details of these experiments and of others like them made with three pairs of differentiating characters are all set out in Mendel's memoir.

Professor de Vries has worked at the same problem in some dozen species belonging to several genera, using pairs of varieties characterized by a great number of characters: for instance, color of flowers, stems, or fruits, hairiness, length of style, and so forth. He states that in all these cases Mendel's principles are followed.

The numbers with which Mendel worked, though large, were not large enough to give really smooth results;[a] but with a few rather marked exceptions the observations are remarkably consistent, and the approximation to the numbers demanded by the law is greatest in those cases where the largest numbers were used. When we consider, besides, that Tschermak and Correns announce definite confirmation in the case of *Pisum*, and de Vries adds the evidence of his long series of observations on other species and orders, there can be no doubt that Mendel's law is a substantial reality; though whether some of the cases that depart most widely from it can be brought within the terms of the same principle or not, can only be decided by further experiments.

One may naturally ask, How can these results be brought into harmony with the facts of hybridization hitherto known; and if all this is true, how is it that others who have carefully studied the phenomena of hybridization have not long ago perceived this law? The answer to this question is given by Mendel at some length, and it is, I think, satisfactory. He admits from the first that there are undoubtedly cases of hybrids and cross-breds which maintain themselves pure and do not break up. Such examples are plainly outside the scope of his law. Next he points out, what to anyone who has rightly comprehended the nature of discontinuity in variation is well known, that the variations in each character must be separately regarded. In most experiments in crossing, forms are taken which differ from each other in a multitude of characters—some continuous, others discontinuous, some capable of blending with their contraries, while others are not. The observer on attempting to perceive any regularity is confused by the complications thus introduced. Mendel's law, as he fairly says, could only appear in such cases by the use of overwhelming numbers, which are beyond the possibilities of practical experiment. Lastly, no previous observer had applied a strict statistical method.

Both these answers should be acceptable to those who have studied the facts of variation and have appreciated the nature of species in the light of those facts. That different species should follow different

[a] Professor Weldon (p. 232) takes great exception to this statement, which he considerately attributes to "some writers." After examining the conclusions he obtained by algebraical study of Mendel's figures I am disposed to think my statement not very far out.

laws and that the same law should not apply to all characters alike is exactly what we have every right to expect. It will also be remembered that the principle is only explicitly declared to apply to discontinuous characters.[a] As stated also, it can only be true where reciprocal crossings lead to the same result. Moreover, it can only be tested when there is no sensible diminution in fertility on crossing.

Upon the appearance of de Vries's paper announcing the "rediscovery" and confirmation of Mendel's law and its extension to a great number of cases, two other observers came forward almost simultaneously and independently described series of experiments fully confirming Mendel's work. Of these papers the first is that of Correns, who repeated Mendel's original experiment with pease having seeds of different colors. The second is a long and very valuable memoir of Tschermak, which gives an account of elaborate researches into the results of crossing a number of varieties of *Pisum sativum*. These experiments were in many cases carried out on a large scale, and prove the main fact enunciated by Mendel beyond any possibility of contradiction. The more exhaustive of these researches are those of Tschermak on peas and correns on several varieties of maize. Both these elaborate investigations have abundantly proved the general applicability of Mendel's law to the character of the plants studied, though both indicate some few exceptions. The details of de Vries's experiments are promised in the second volume of his most valuable *Mutationstheorie*. Correns in regard to maize and Tschermak in the case of *P. sativum* have obtained further proof that Mendel's law holds as well in the case of varieties differing from each other in two pairs of characters, one of each pair being dominant, though of course a more complicated expression is needed in such cases.[b]

That we are in the presence of a new principle of the highest importance is manifest. To what further conclusions it may lead us can not yet be foretold. But both Mendel and the authors who have followed him lay stress on one conclusion, which will at once suggest itself to anyone who reflects on the facts. For it will be seen that the results are such as we might expect if it be imagined that the cross-bred plant produced pollen grains and egg cells, each of which bears only one of the alternative varietal characters and not both. If this were so, and if on an average the same number of pollen grains and egg cells transmit each of the two characters, it is clear that on a random assortment of pollen grains and egg cells Mendel's law would be obeyed. For 25 per cent of "dominant" pollen grains would unite with 25 per cent

[a] See later.

[b] Tschermak's investigations were besides directed to a reexamination of the question of the absence of beneficial results on cross-fertilizing *P. sativum*, a subject already much investigated by Darwin, and upon this matter also important further evidence is given in great detail.

"dominant" egg cells; 25 per cent "recessive" pollen grains would similarly unite with 25 per cent "recessive" egg cells; while the remaining 50 per cent of each kind would unite together. It is this consideration which leads both Mendel and those who have followed him to assert that these facts of crossing prove that each egg cell and each pollen grain is pure in respect of each character to which the law applies. It is highly desirable that varieties differing in the form of their pollen should be made the subject of these experiments, for it is quite possible that in such a case strong confirmation of this deduction might be obtained. [Preliminary trials made with reference to this point have so far given negative results. Remembering that a pollen grain is not a germ cell, but only a bearer of a germ cell, the hope of seeing pollen grains differentiated according to the characters they bear is probably remote. Better hopes may perhaps be entertained in regard to spermatozoa, or possibly female cells.]

As an objection to the deduction of purity of germ cells, however, it is to be noted that though true intermediates did not generally occur, yet the intensity in which the characters appeared did vary in degree, and it is not easy to see how the hypothesis of perfect purity in the reproductive cells can be supported in such cases. Be this, however, as it may, there is no doubt we are beginning to get new lights of a most valuable kind on the nature of heredity and the laws which it obeys. It is to be hoped that these indications will be at once followed up by independent workers. Enough has been said to show how necessary it is that the subjects of experiment should be chosen in such a way as to bring the laws of heredity to a real test. For this purpose the first essential is that the differentiating characters should be few, and that all avoidable complications should be got rid of. Each experiment should be reduced to its simplest possible limits. The results obtained by Galton, and also the new ones especially described in this paper, have each been reached by restricting the range of observation to one character or group of characters, and it is certain that by similar treatment our knowledge of heredity may be rapidly extended.

To the above popular presentation of the essential facts, made for an audience not strictly scientific, some addition, however brief, is called for. First, in regard to the law of ancestry, spoken of on a preceding page. Those who are acquainted with Pearson's Grammar of Science, second edition, published early in 1900, the same author's paper in Proceedings Royal Society, volume 66, 1800, page 140, or the extensive memoir (published October, 1900), on the inheritance of coat color in horses and eye color in man (Phil. Trans., 195, A, 1900, p. 79), will not need to be told that the few words I have given above constitute a most imperfect diagram of the operations of that law as now developed. Until the appearance of these treatises it was, I

believe, generally considered that the law of ancestral heredity was to be taken as applying to phenomena like these (coat color, eye color, etc.) where the inheritance is generally alternative, as well as to the phenomena of blended inheritance.

Pearson, in the writings referred to, besides withdrawing other large categories of phenomena from the scope of its operations, points out that the law of ancestral heredity does not satisfactorily express the cases of alternative inheritance. He urges, and with reason, that these classes of phenomena should be separately dealt with.

The whole issue as regards the various possibilities of heredity now recognized will be made clearer by a very brief exposition of the several conceptions involved.

If an organism producing germ-cells of a given constitution, uniform in respect of the characters they bear, breeds with another organism[a] bearing precisely similar germ-cells, the offspring resulting will, if the conditions are identical, be uniform.

In practice such a phenomenon is seen in pure breeding. It is true that we know no case in nature where all the germ-cells are thus identical, and where no variation takes place beyond what we can attribute to conditions, but we know many cases where such a result is approached, and very many where all the essential features which we regard as constituting the characters of the breed are reproduced with approximate certainty in every member of the pure-bred race, which thus closely approach to uniformity.

But if two germ-cells of dissimilar constitution unite in fertilization, what offspring are we to expect?[b] First let us premise that the answer to this question is known experimentally to differ for many organisms and for many classes of characters, and may almost certainly be in part determined by external circumstances. But omitting the last qualification, certain principles are now clearly detected, though what principle will apply in any given case can only be determined by direct experiment made with that case.

This is the phenomenon of cross breeding. As generally used, this term means the union of members of dissimilar varieties, or species; though when dissimilar gametes[c] produced by two individuals of the same variety unite in fertilization, we have essentially cross breeding in respect of the character or characters in which those gametes differ. We will suppose, as before, that these two gametes bearing

[a] For simplicity the case of self-fertilization is omitted from this consideration.

[b] In all the cases discussed it is assumed that the gametes are similar except in regard to the "heritage" they bear, and that no original variation is taking place. The case of mosaics is also left wholly out of account (see later).

[b] The term "gamete" is now generally used as the equivalent of "germ-cell," whether male or female, and the term "zygote" is here used for brevity to denote the organism resulting from fertilization.

properties unlike in respect of a given character are borne by different individuals.

In the simplest case, suppose a gamete from an individual presenting any character in intensity *A* unite in fertilization with another from an individual presenting the same character in intensity *a*. For brevity's sake we may call the parent individuals *A* and *a* and the resulting zygote *Aa*. What will the structure of *Aa* be in regard to the character we are considering?

Up to Mendel no one proposed to answer this question in any other way than by reference to the intensity of the character in the progenitors and primarily in the parents, *A* and *a*, in whose bodies the gametes had been developed. It was well known that such a reference gave a very poor indication of what *Aa* would be. Both *A* and *a* may come from a population consisting of individuals manifesting the same character in various intensities. In the pedigree of either *A* or *a* these various intensities may have occurred few or many times. Common experience leads us to expect the probability in regard to *Aa* to be influenced by this history. The next step is that which Galton took. He extended the reference beyond the immediate parents of *Aa* to its grandparents, great-grandparents, and so on, and in the cases he studied he found that from a knowledge of the intensity in which the given character was manifested in each progenitor, even for some few generations back, a fairly accurate prediction could be made, not as to the character of any individual *Aa*, but as to the average character of *Aa*'s of similar parentage in general.

But suppose that instead of individuals presenting one character in differing intensities, two individuals breed together, distinguished by characters which we know to be mutually exclusive, such as *A* and *B*. Here again we may speak of the individuals producing the gametes as *A* and *B* and the resulting zygote as *AB*. What will *AB* be like? The population here again may consist of many like *A* and like *B*. These two forms may have been breeding together indiscriminately, and there may have been many or few of either type in the pedigree of either *A* or *B*.

Here again Galton applied his method with remarkable success. Referring to the progenitors of *A* and *B*, determining how many of each type there were in the direct pedigree of *A* and of *B*, he arrived at the same formula as before, with the simple difference that instead of expressing the probable average intensity of one character in several individuals, the prediction is given in terms of the probable number of *A*'s and *B*'s that would result on an average when particular *A*'s and *B*'s of known pedigree breed together.

The law as Galton gives it is as follows:

"It is that the two parents contribute between them on the average

one-half or (0.5) of the total heritage of the offspring; the four grandparents, one quarter or $(0.5)^2$; the eight great-grandparents, one-eighth or $(0.5)^3$, and so on. Then the sum of the ancestral contributions is expressed by the series

$$\{(0.5) + (0.5)^2 + (0.5)^3, \text{ etc.}\},$$

which, being equal to 1, accounts for the whole heritage."

In the former case where A and a are characters which can be denoted by reference to a common scale, the law assumes of course that the inheritance will be, to use Galton's term, blended; namely, that the zygote resulting from the union of A with a will on the average be more like a than if A had been united with A; and, conversely, that an Aa zygote will on the average be more like A than an aa zygote would be.

But in the case of A's and B's, which are assumed to be mutually exclusive characters, we can not speak of blending, but rather, to use Galton's term, of alternative inheritance.

Pearson, finding that the law, whether formulated thus or in the modified form in which he restated it,[a] did not express the phenomena of alternative inheritance known to him with sufficient accuracy to justify its strict application to them, and also on general grounds proposed that the phenomena of blended and alternative inheritance should be treated apart—a suggestion[b] the wisdom of which can scarcely be questioned.

Now the law thus imperfectly set forth and every modification of it is incomplete in one respect. It deals only with the characters of the resulting zygotes and predicates nothing in regard to the gametes which go to form them. A good prediction may be made as to any given group of zygotes, but the various possible constitutions of the gametes are not explicitly treated.

Nevertheless a definite assumption is implicitly made regarding the gametes. It is not in question that differences between these gametes may occur in respect of the heritage they bear, yet it is assumed that these differences will be distributed among the gametes of any individual zygote in such a way that each gamete remains capable on fertilization of transmitting all the characters (both of the parent zygote and of its progenitors) to the zygote which it then contributes to form (and to the posterity of that zygote) in the intensity indicated by the law. Hence, the gametes of any individual are taken as collectively a fair sample of all the racial characters in their appropriate intensities, and this theory demands that there shall have been no qualitative redistribution of characters among the gametes of any zygote in such

[a] In Pearson's modification the parents contribute 0.3, the grandparents, 0.15, the great-grandparents 0.075.

[b] See the works referred to above.

a way that some gametes shall be finally excluded from partaking of and transmitting any specific part of the heritage. The theory further demands—and by the analogy of what we know otherwise not only of animals and plants, but of physical or chemical laws, perhaps this is the most serious assumption of all - that the structure of the gametes shall admit of their being capable of transmitting any character in any intensity varying from zero to totality with equal ease, and that gametes of each intensity are all equally likely to occur, given a pedigree of appropriate arithmetical composition.

Such an assumption appears so improbable that even in cases where the facts seem as yet to point to this conclusion with exceptional clearness, as in the case of human stature, I can not but feel there is still room for reserve of judgment.

However this may be, the law of ancestral heredity and all modifications of it yet proposed falls short in the respect specified above—that it does not directly attempt to give any account of the distribution of the heritage among the gametes of any one individual.

Mendel's conception differs fundamentally from that involved in the law of ancestral heredity. The relation of his hypothesis to the foregoing may be most easily shown if we consider it first in application to the phenomena resulting from the cross breeding of two pure varieties.

Let us again consider the case of two varieties, each displaying the same character, but in the respective intensities A and a. Each gamete of the A variety bears A, and each gamete of the a variety bears a. When they unite in fertilization they form the zygote Aa. What will be its characters? The Mendelian teaching would reply that this can only be known by direct experiment with the two forms A and a, and that the characters A and a perceived in those two forms or varieties need not give any indication as to the character of the zygote Aa. It may display the character A or a or a character halfway between the two, or a character beyond A or below a. The character of Aa is not regarded as a heritage transmitted to it by A and by a, but as a character special and peculiar to Aa, just as NaCl is not a body halfway between sodium and chlorine, or such that its properties can be predicted from or easily stated in terms of theirs.

If a concrete case may help, a tall pea A crossed with a dwarf a often produces not a plant having the height of either A or a, but something taller than the pure tall variety A.

But if the case obeys the Mendelian principles—as does that here quoted—then it can be declared, first, that the gametes of Aa will not be bearers of the character proper to Aa; but, generally speaking, each gamete will either bear the pure A character or the pure a character. There will in fact be a redistribution of the characters brought in by the gametes which united to form the zygote Aa, such that each gamete of Aa is pure, as the parental gametes were. Secondly, this

redistribution will occur in such a way that of the gametes produced by such Aa's, on an average there will be equal numbers of A gametes and of a gametes.

Consequently if Aa's breed together, the new A gametes may meet each other in fertilization, forming a zygote AA, namely, the pure A variety again. Similarly two a gametes may meet and form aa, or the pure a variety again. But if an A gamete meets an a, it will once more form Aa, with its special character. This Aa is the hybrid or "mule" form, or, as I have elsewhere called it, the heterozygote, as distinguished from AA or aa the homozygotes.

Similarly if the two gametes of two varieties distinguished by characters A and B, which can not be described in terms of any common scale—such as, for example, the "rose" and "single" combs of fowls—unite in fertilization, again the character of the mule form can not be predicted. Before the experiment is made the "mule" may present any form. Its character or properties can as yet be no more predicted than could those of the compounds of unknown elements before the discovery of the periodic law.

But again—if the case be Mendelian—the gametes borne by AB will be either A's or B's,[a] and the cross-bred AB's breeding together will form AA's, AB's, and BB's. Moreover, if, as in the normal Mendelian case, AB's bear on an average equal numbers of A gametes and B gametes, the numerical ratio of these resulting zygotes to each other will be

$$1\,AA : 2\,AB : 1\,BB.$$

We have seen that Mendel makes no prediction as to the outward and visible characters of AB, but only as to the essential constitution and statistical condition of its gametes in regard to the characters A and B. Nevertheless in a large number of cases the character of AB is known to fall into one of three categories (omitting mosaics).

(1) The cross-bred may almost always resemble one of its pure parents so closely as to be practically indistinguishable from that pure form, as in the case of the yellow cotyledon-color of certain varieties of peas when crossed with green-cotyledoned varieties; in which case the parental character, yellow, thus manifested by the cross bred is called "dominant," and the parental character, green, not manifested, is called recessive.

(2) The crossbred may present some condition intermediate between the two parental forms, in which case we may still retain the term "blend" as applied to the zygote.

Such an "intermediate" may be the apparent mean between the two parental forms, or be nearer to one or other in any degree. Such a

[a] This conception was clearly formed by Naudin simultaneously with Mendel, but it was not worked out by him and remained a mere suggestion. In one place also Focke came very near to the same idea. (See Bibliography.)

case is that of a cross between a rich crimson magenta Chinese primrose and a clear white, giving a flower of a color appropriately described as a "washy" magenta.

(3) The crossbred may present some form quite different from that of either pure parent. Though, as has been stated, nothing can be predicted of an unknown case, we already know a considerable number of examples of this nature in which the mule form approaches sometimes with great accuracy to that of a putative ancestor, near or remote. It is scarcely possible to doubt that several—though perhaps not all—of Darwin's "reversions on crossing" were of this nature.

Such a case is that of the "wild gray mouse" produced by the union of an albino tame mouse and a piebald Japanese mouse.[a] These "reversionary" mice bred together produce the parental tame types, some other types, and "reversionary" mice again.

From what has been said it will now be clear that the applicability of the Mendelian hypothesis has, intrinsically, nothing whatever to do with the question of the inheritance being blended or alternative. In fact, as soon as the relation of zygote characters to gamete characters is appreciated, it is difficult to see any reason for supposing that the manifestation of characters seen in the zygotes should give any indication as to their mode of allotment among the gametes.

On a previous occasion I pointed out that the terms "heredity" and "inheritance" are founded on a misapplication of metaphor, and in the light of our present knowledge it is becoming clearer that the ideas of "transmission" of a character by parent to offspring, or of there being any "contribution" made by an ancestor to its posterity, must only be admitted under the strictest reserve, and merely as descriptive terms.

We are now presented with some entirely new conceptions:

(1) The purity of the gametes in regard to certain characters.

(2) The distinction of all zygotes according as they are or are not formed by the union of like or unlike gametes. In the former case, apart from variation, they breed true when mated with their like; in the latter case their offspring, collectively, will be heterogeneous.

(3) If the zygote be formed by the union of dissimilar gametes, we may meet the phenomenon of (*a*) dominant and recessive characters; (*b*) a blend form; (*c*) a form distinct from either parent, often reversionary.[b]

[a] See von Guaita, Ber. Naturf. Ges. Freiburg, X, 1898, and XI, 1899, quoted by Professor Weldon (see later).

[b] This fact sufficiently indicates the difficulties involved in a superficial treatment of the phenomenon of reversion. To call such reversions as those named above "returns to ancestral type" would be, if more than a descriptive phrase were intended, quite misleading. It is not the ancestral type that has come back, but something else has come in its guise, as the offspring presently prove. For the first time we thus begin to get a rationale of "reversion."

But there are additional and even more significant deductions from the facts. We have seen that the gametes are differentiated in respect of pure characters. Of these pure characters there may conceivably be any number associated together in one organism. In the pea Mendel detected at least seven — not all seen by him combined in the same plant; but there is every likelihood that they are all capable of being thus combined.

Each such character, which is capable of being dissociated or replaced by its contrary, must henceforth be conceived of as a distinct unit character; and as we know that the several unit characters are of such a nature that any one of them is capable of independently displacing or being displaced by one or more alternative characters taken singly, we may recognize this fact by naming such unit characters allelomorphs. So far we know very little of any allelomorphs existing otherwise than as pairs of contraries, but this is probably merely due to experimental limitations and the rudimentary state of our knowledge.

In one case (combs of fowls) we know three characters—pea comb, rose comb, and single comb, of which pea and single, or rose and single, behave toward each other as a pair of allelomorphs, but of the behavior of pea and rose toward each other we know as yet nothing.

We have no reason as yet for affirming that any phenomenon properly described as displacement of one allelomorph by another occurs, though the metaphor may be a useful one. In all cases where dominance has been perceived we can affirm that the members of the allelomorphic pair stand to each other in a relation the nature of which we are as yet wholly unable to apprehend or illustrate.

To the new conceptions already enumerated we may therefore add:

(4) Unit characters, of which some, when once arisen by variation, are alternative to each other in the constitution of the gametes, according to a definite system.

From the relations subsisting between these characters it follows that as each zygotic union of allelomorphs is resolved on the formation of the gametes, no zygote can give rise to gametes collectively representing more than two characters allelomorphic to each other, apart from new variation.

From the fact of the existence of the interchangeable characters we must, for purposes of treatment and to complete the possibilities, necessarily form the conception of an irresoluble base, though whether such a conception has any objective reality we have no means as yet of determining.

We have now seen that when the varieties A and B are crossed together, the heterozygote AB produces gametes bearing the pure A character and the pure B character. In such a case we speak of such characters as simple allelomorphs. In many cases, however, a more complex phenomenon happens. The character brought in on fertilization by one or other parent may be of such a nature that when the

zygote AB forms its gametes, these are not individually bearers merely of A and B, but of a number of characters themselves again integral, which in, say A, behaved as one character so long as its gametes united in fertilization with others like themselves, but on cross fertilization are resolved and redistributed among the gametes produced by the cross-bred zygote.

In such a case we call the character A a compound allelomorph, and we can speak of the integral characters which constitute it as hypallelomorphs. We ought to write the heterozygote $(AA'A''\ldots)\ B$ and the gametes produced by it may be of the form A, A', A'', A''',.... B. Or the resolution may be incomplete in various degrees, as we already suspect from certain instances; in which case we may have gametes A, $A'A''$, $A'''A''''$, $A'A''A^{v}$,... B, and so on. Each of these may meet a similar or a dissimilar gamete in fertilization, forming either a homozygote or a heterozygote with its distinct properties.

In the case of compound allelomorphs we know as yet nothing of the statistical relations of the several gametes.

Thus we have the conception

(5) of a Compound character, borne by one gamete, transmitted entire as a single character so long as fertilization only occurs between like gametes, or is, in other words, "symmetrical;" but if fertilization take place with a dissimilar gamete (or possibly by other causes), resolved into integral constituent characters, each separately transmissible.

Next, as, by the union of the gametes bearing the various hypallelomorphs with other such gametes, or with gametes bearing simple allelomorphs, in fertilization, a number of new zygotes will be formed, such as may not have been seen before in the breed. These will inevitably be spoken of as varieties; and it is difficult not to extend the idea of variation to them. To distinguish these from other variations—which there must surely be—we may call them

(6) Analytical variations in contradistinction to

(7) Synthetical variations, occurring not by the separation of preexisting constituent characters, but by the addition of new characters.

Lastly, it is impossible to be presented with the fact that in Mendelian cases the crossbred produces on an average equal numbers of gametes of each kind—that is to say, a symmetrical result—without suspecting that this fact must correspond with some symmetrical figure of distribution of those gametes in the cell divisions by which they are produced.

At the present time these are the main conceptions—though by no means all—arising directly from Mendel's work. The first six are all more or less clearly embodied by him, though not in every case developed in accordance with modern knowledge. The seventh is not a Mendelian conception, but the facts before us justify its inclusion in

the above list, though for the present it is little more than a mere surmise.

In Mendelian cases it will now be perceived that all the zygotes composing the population consist of a limited number of possible types, each of definite constitution, bearing gametes also of a limited and definite number of types, and definite constitution in respect of preexisting characters. It is now evident that in such cases each several progenitor need not be brought to account in reckoning the probable characters of each descendant; for the gametes of crossbreds are differentiated at each successive generation, some parental (Mendelian) characters being left out in the composition of each gamete produced by a zygote arising by the union of bearers of opposite allelomorphs.

When from these considerations we return to the phenomena comprised in the law of ancestral heredity, what certainty have we that the same conceptions are not applicable there also?

It has now been shown that the question whether in the crossbred zygotes in general the characters blend or are mutually exclusive is an entirely subordinate one, and distinctions with regard to the essential nature of heredity based on these circumstances become irrelevant.

In the case of a population presenting continuous variation in regard to, say, stature, it is easy to see how purity of the gametes in respect of any intensities of that character might not in ordinary circumstances be capable of detection. There are doubtless more than two pure gametic forms of this character, but there may quite conceivably be six or eight. When it is remembered that each heterozygous combination of any two may have its own appropriate stature, and that such a character is distinctly dependent on external conditions, the mere fact that the observed curves of stature give "chance distributions" is not surprising and may still be compatible with purity of gametes in respect of certain pure types. In peas (*P. sativum*), for example, from Mendel's work we know that the tall forms and the extreme dwarf forms exhibit gametic purity. I have seen at Messrs. Sutton's strong evidence of the same nature in the case of the tall sweet pea (*Lathyrus odoratus*) and the dwarf or procumbent "Cupid" form.

But in the case of the sweet pea we know at least one pure form of definitely intermediate height, and in the case of *P. sativum* there are many. When the extreme types breed together it will be remembered the heterozygote commonly exceeds the taller in height. In the next generation, since there is in the case of extremes, so much margin between the types of the two pure forms, the return of the offspring to the three forms, of which two are homozygous and one heterozygous, is clearly perceptible.

If, however, instead of pure extreme varieties, we were to take a pair of varieties differing normally by only a foot or two, we might,

owing to the masking effects of conditions, etc., have great difficulty in distinguishing the three forms in the second generation. There would, besides, be twice as many heterozygous individuals as homozygous individuals of each kind, giving a symmetrical distribution of heights, and who might not—in pre-Mendelian days—have accepted such evidence, made still less clear by influence of conditions, as proof of continuous variation both of zygotes and gametes?

Suppose, then, that instead of two pure types, we had six or eight breeding together, each pair forming their own heterozygote, there would be a very remote chance of such purity or fixity of type, whether of gamete or zygote, being detected.

Dominance, as we have seen, is merely a phenomenon incidental to specific cases, between which no other common property has yet been perceived. In the phenomena of blended inheritance we clearly have no dominance. In the cases of alternative inheritance studied by Galton and Pearson there is evidently no universal dominance. From the tables of Basset hound pedigrees there is clearly no definite dominance of either of the coat colors. In the case of eye color the published tables do not, so far as I have discovered, furnish the material for a decision, though it is scarcely possible the phenomenon, even if only occasional, could have been overlooked. We must take it, then, there is no sensible dominance in these cases; but whether there is or is not sensible gametic purity is an altogether different question, which, so far as I can judge, is as yet untouched. It may perfectly well be that we shall be compelled to recognize that in many cases there is no such purity, and that the characters may be carried by the gametes in any proportion from zero to totality, just as some substances may be carried in a solution in any proportion from zero to saturation without discontinuous change of properties. That this may be found true in some cases is, on any hypothesis, certain; but to prove the fact for any given case will be an exceedingly difficult operation, and I scarcely think it has been yet carried through in such a way as to leave no room for doubt.

Conversely, the absolute and universal purity of the gametes has certainly not yet been determined for any case; not even in those cases where it looks most likely that such universal purity exists. Impairment of such purity we may conceive either to occur in the form of mosaic gametes, or of gametes with blended properties. On analogy and from direct evidence we have every right to believe that gametes of both these classes may occur in rare and exceptional cases, of as yet unexplored nature,[a] but such a phenomenon will not diminish the significance of observed purity.

[a] It will be understood from what follows that the existence of mosaic zygotes is no proof that either component gamete was mosaic.

We have now seen the essential nature of the Mendelian principles and are able to appreciate the exact relation in which they stand to the group of cases included in the law of ancestral heredity. In seeking any general indication as to the common properties of the phenomena which are already known to obey Mendelian principles we can as yet point to none, and whether some such common features exist or not is unknown.

There is, however, one group of cases, definite though as yet not numerous, where we know that the Mendelian principles do not apply. These are the phenomena upon which Mendel touches in his brief paper on Hieracium. As he there states, the hybrids, if they are fertile at all, produce offspring like themselves, not like their parents. In further illustration of this phenomenon he cites Wichura's Salix hybrids. Perhaps some dozen other such illustrations could be given which rest on good evidence. To these cases the Mendelian principle will in no wise apply, nor is it easy to conceive any modification of the law of ancestral heredity which can express them. There the matter at present rests. Among these cases, however, we perceive several more or less common features. They are often, though not always, hybrids between forms differing in many characters. The first cross frequently is not the exact intermediate between the two parental types, but may, as in the few Hieracium cases, be irregular in this respect. There is often some degree of sterility. In the absence of fuller and statistical knowledge of such cases further discussion is impossible.

Another class of cases, untouched by any hypothesis of heredity yet propounded, is that of the false hybrids of Millardet, where we have fertilization without transmission of one or several parental characters. In these not only does the first cross show, in some respect, the character or characters of one parent only, but in its posterity no reappearance of the lost character or characters is observed. The nature of such cases is still quite obscure, but we have to suppose that the allelomorph of one gamete only develops after fertilization to the exclusion of the corresponding allelomorph of the other gamete, much—if the crudity of the comparison may be pardoned—as occurs on the female side in parthenogenesis without fertilization at all.

To these as yet altogether unconformable cases we can scarcely doubt that further experiment will add many more. Indeed, we already have tolerably clear evidence that many phenomena of inheritance are of a much higher order of complexity. When the paper on Pisum was written Mendel apparently inclined to the view that with modifications his law might be found to include all the phenomena of hybridization, but in the brief subsequent paper on Hieracium he clearly recognized the existence of cases of a different nature. Those who read that contribution will be interested to see that he lays down

a principle which may be extended from hybridization to heredity in general, that the laws of each new case must be determined by separate experiment.

As regards the Mendelian principles, which it is the chief aim of this introduction to present clearly before the reader, a professed student of variation will easily be able to fill in the outline now indicated, and to illustrate the various conceptions from phenomena already familiar. To do this is beyond the scope of this short sketch, but enough perhaps has now been said to show that by the application of those principles we are enabled to reach and deal in a comprehensive manner with phenomena of a fundamental nature, lying at the very root of all conceptions not merely of the physiology of reproduction and heredity, but even of the essential nature of living organisms; and I think that I used no extravagant words when, in introducing Mendel's work to the notice of readers of the Royal Horticultural Society's Journal, I ventured to declare that his experiments are worthy to rank with those which laid the foundation of the atomic laws of chemistry.

THE MORPHOLOGICAL METHOD AND RECENT PROGRESS IN ZOOLOGY.[a]

By Prof. G. B. Howes, D. Sc., LL. D., F. R. S.

It is now twenty-eight years since this association last assembled in Belfast, and to those present who can recall the meeting, the proceedings of Section D will be best remembered for the delivery of an address by Huxley "On the hypothesis that animals are automata, and its history," one of the finest philosophic products of his mind. At that date the zoological world was about to embark on a period of marked activity. Fired by the influence of the "Origin of Species," which had survived abuse and was taking immediate effect, the zoological mind, accepting the doctrine of evolution, had become eager to determine the lines of descent of animal forms. Marine observatories were in their infancy; the *Challenger* was still at sea; the study of comparative embryology was but then becoming a science; and when, reflecting on this, we briefly survey the present field, we can but stand astonished at the enormity of the task which has been achieved.

Development has proceeded on every hand. The leavening influence, spreading with sure effect, has in due course extended to the antipodes and the East, in each of which portions of the globe there have now arisen a band of earnest workers pledged to the investigation of their indigenous fauna, with which they are proceeding with might and main. Of the Japanese, let it be said that not only have they filled in gaps in our growing knowledge, for which they alone have the materials at hand, but that, with an acumen deserving the highest praise, they have put us right on first principles. I refer to the fact that they have shown, with respect to the embryonic membranes of the common chick, that we in the West, with our historic associations, our methods, and our skill, contenting ourselves with an ever-recurring restriction to the germinal area, have, by an error of orientation, missed an all-important septum, displaced under an inequality of growth.

[a] Address to Zoological Section of the British Association for the Advancement of Science, by Professor Howes, president of the section, at Belfast, 1902. Reprinted from Report of the British Association, pp. 618–635.

Those of us who have lived and worked throughout this memorable period have had a unique experience, for never has there been progress so rapid, accumulation of observations so extensive and exact. Of the 386,000 living animal species, to compute the estimate low, every one available has been lain under hand, with the result that our annual literary output now amounts to close upon 10,000 contributions, the description of new genera and subgenera, say 1,700. More than one-half of this vast series refer to the Insecta alone; but notwithstanding this, the records of facts of structure and development, with which most of us are concerned, now amount to a formidable mass, calculated to awe the unlettered looker-on, to overwhelm the earnest devotee, unless by specializing he can secure relief. As an example of what may occur, it may be remarked that a recent exploration of the great African lakes has resulted in the discovery of over 130 new species.

As to the nature of this unprecedented progress, it will suffice to consider the Earthworms. In 1874 few were known to us. An advance in our knowledge, which had then commenced, had made known but few more which seemed likely to yield result. Darwin's book upon them had not appeared. Some were exotic, it is true, but no one suspected that a group so restricted in their habits could reveal aught beyond a dull monotony of form and structure. Never was surmise more wide of the mark, for the combined investigations of a score of earnest workers in all parts of the world have in the interval recorded some 700 odd species of about 140 genera. Mainly exotic, they exhibit among themselves a structural variation of the widest possible range. Not only do we recognize littoral and branchiate forms, but others achætous and leech-like in habit, to the extent of the discovery of a morphological overlap with the leeches, under which we are now compelled to remove them from their old association with the flat worms, and to unite them with the earthworms. And we even find these animals, as represented by the *Acanthodrilidæ*, coming prominently into considerations which involve the theory of a former antarctic continent, one of the most revolutionary zoo-geographical topics of our time.

This case of the earthworm may be taken as typical of the rest, since for each and every class and order of animal forms the progress of the period through which we have passed since last we assembled here has produced revolutionary results. Our knowledge of facts has become materially enhanced; our classifications, at best but the working expression of our ideas, have been to a large extent replaced in clearer, more comprehensive, schemes; and we are to-day enabled to deduce, with an accuracy proportionate to our increased knowledge of fact, the nature of the interrelationships of the living forms which with ourselves inhabit the earth.

Satisfactory as is this result, it must be clearly born in mind that its realization could not have come about but for a knowledge of the animals of the past. And turning now to paleontology, it may be said that at the time of our last meeting in this city the scientific world was just becoming entranced by the promise of unexpected results in the exploration of the American Tertiary beds, then being first opened up. The Rocky Mountain district was the area under investigation, and with this, as with the progress in our knowledge of recent forms, no one living was prepared for the discoveries which shortly came to pass. To consider a concrete case, we may premise that study of the placental mammals had justified the conclusion that their ancestors must have had equal and pentadactyle limbs, a complete ulna and fibula, a complete clavicle, and a skull with 44 teeth must have realized, that is, the predominant term of the living insectivora as generally understood. Who among the zoologists of our time does not recall with enthusiasm the revelation which arose from the discovery, during these early days, in the Eocene of central North America, of the genera at first described as *Eo-* and *Helohyus?* The evidence of the existence, in the locality named, of these 44-toothed peccaries, as they were held to be, rendered clearer the records of the later Tertiary deposits of the Old World, which were those of hogs, and, in correlation with the facts then known, suggested that the Rocky Mountain area was the home of the ancestral porcine stock, and that in early Tertiary times their descendants must have migrated, on the one hand, across the northern belt, of which the Aleutian Islands now mark the course, into the Old World, to beget, by complication of their teeth, the pigs and hogs; and on the other into central South America, to give rise, by numerical reduction of teeth and toes, to the peccaries, still extant.

Migration in opposite directions with diversity of modification was the refrain of this remarkable find, far-reaching in its morphological and zoo-geographical effects. Nor can we allude with less fervor to the still more striking case of the horses, which proved not merely a similar, though perhaps a later, migration, but a parallelism of modification in both the Old and New worlds, culminating in the latter in extinction, whereby it became necessary, on the advent of civilized man, to carry back the Old World horse to its ancestral American home. No wonder that this should have provoked our Huxley to the remark that in it we have the "demonstrative evidence of the occurrence of evolution," and that the facts of paleontology came to be regarded as certainly not second to those of the fascinating but seductive department of embryology, at the time making giant strides.

I have endeavored thus to picture that state of zoological science at the time of our last meeting here, and I wish now to confine myself to some of the broader results since achieved on the morphological side.

But let us first digress, in order to be clear as to the meaning of this phrase.

We do not expect the public to be accurate in their usage of scientific terms; but it is to me an astounding fact that among trained scientific experts, devotees to branches of science other than our own, there exists a gross misunderstanding as to the limitations of our departments. I quote from an official report in alluding to "comparative anatomists, or biologists, as they call themselves," and I but cite the words of an eminent scientific friend in referring to biology and botany as coequal. In endeavoring to get rid of this prevailing error, let it be once more said that the term "biology" was introduced at the beginning of the nineteenth century by Treviranus and Lamarck, and that in its usage it has come to signify two totally distinct things as employed by our continental contemporaries and ourselves. By "biologie" they understand the study of the organism in relation to its environment. We, following Huxley, include in our term biology the study of all phenomena manifested by living matter; botany and zoology; and by morphology we zoologists mean the study of structure in all its forms, of anatomy, histology, and development, with paleontology—of all, that is, which can be preferably studied in the dead state—as distinct from physiology, the study of the living in action. Comparative morphology, the study of likeness and unlikeness, is the basis of our working classifications, and it is to the consideration of the morphological method and the more salient of its recent results that I would now proceed, in so far as it may be said to have marked progress and given precision to our ideas within the last eight and twenty years. I would deal in the main with facts, with theories only where self-evident, ignoring that type of generalization to which the exclusive study of embryology has lent itself, which characterizes, but does not grace, a vast portion of our recent zoological literature.

To the earnest student of zoology intent on current advance, the mental image of the interrelationships of the greater groups of animal forms is ever changing—kaleidoscopically it may be—but with diminishing effect in proportion as our knowledge becomes the more precise.

Returning now to American paleontology, we may at once continue our theme. In this vast field expedition after expedition has returned with material rich and plentiful. And while by study of it our knowledge of every living mammalian order, to say the least, has been extended, and in some cases revolutionized, we have come to regard the early Tertiary period as the heyday of the mammals in the sense that the present epoch is that of the smaller birds. No wonder, then, that there should have been discovered group after group which has become extinct, or evidence that in matters such as tooth structure there is reason to believe that types identical with those of to-day have been previously evolved, but to disappear. To contemplate the

discovery of the Titanotheria, the Amblyopoda, the Dinocerata, with their strange diminutive brain, chief among the heavier ungulate forms, is to consider the Mammalia anew; and when it is found that among late discoveries we have (1) that of a series of Rhinoceratoidea, which, though not yet known to extend so far back in time as the primitive tapirs and horses, are complete as far as they go; (2) that among the Ruminants we have, in the Oreodontidæ of the American Eocene, primitive forms with a dentition of 44 teeth, an absence of diastemata, a pentadactyle manus, a tetradactyle pes with traces of a hallux, and, as would appear from an example of *Mesoreodon*, a bony clavicle, such as is unknown in any later ungulate, we are aroused to a pitch of eager enthusiasm as to the outcome of labors now in hand; for as I write there reaches me a letter to the effect that for most of the great vertebrate groups, and not the mammals alone, collections are still coming in, each more wonderful than the last.

In the extension of our knowledge of the Ancylopoda, an order of mammals named after the *Ancylotherium* of Pikermi and Samos, which occur in the early Tertiary deposits of Europe, Asia, North America, and abundantly in Patagonia, we have been made aware of the existence of genera whose salient structural features combine the dentition of an ungulate with the possession of pointed claws, believed to have been retractile, like those of the living cats. Conversely to these unguiculate herbivores, which include genera with limbs on both the artio- and perisso-dactyle lines, there have been found among the so-called Mesonychidæ undoubted primitive carnivores, indications of a type of terminal phalanx seal like and approximately nonunguiculate; from all of which it is clear that we have in the rocks the remains of forms extinct which transpose the correlations of tooth and claw deducible from the living orders alone. Further among the primitive pentadactyle Carnivora we meet, in the genus *Patriofelis*, with a reduction of the lower incisors to two, and characters of the fore limb which, with this, suggest the seals. It is, however, probable that these characters are in no way indicative of direct genetic relationship between the two, for inasmuch as these animals were accustomed to seek their food in the water of the lake by which they dwelt, their seal-like characters may be but the expression of adaptation to a partially aquatic mode of life —of parallelism of modification with the seals, and nothing more.

Early in the history of their inquiry our American confrères recorded from the Pliocene the discovery of camel-like forms possessed of a full upper incisor dentition—for example, the genera *Protolabis* and *Ithygrammodon*—and now they have arrived at the conclusion that while the camels are of American origin one of their most characteristic ruminants, the Prongbuck (*Antilocapra*), would conversely appear to be the descendant of an ancestor (*Blastomeryx*) that migrated from the Old World.

Sufficient this concerning the work in mammalogy of the American paleontologists. While we return them our devout and learned admiration, we would point out that the brilliance of their discoveries has but beclouded the recognition of equally important investigations going on elsewhere. In Argentina there have proceeded, side by side with the North American explorations, researches into the Pleistocene or Pampa fauna, which in result are not one whit behind, as has been proved by the recognition of a whole order of primitive ungulates, the Toxodontia, by that of toothed cetaceans with elongated nasals, as in the genera *Prosqualodon* and *Argyrocetus*, and of sperm whales with functional premaxillary teeth, viz, *Physodon* and *Hyperoetus*, to say nothing of giant armadillos and pigmy glyptodons.

It will be remembered by some present that from Patagonian deposits of supposed Cretaceous age there was exhibited at our Dover meeting the skull of a horned chelonian *Meiolania*, which animal, we were informed, is barely distinguishable from the species originally discovered in Cooks Island, one of the Society group, and which, being a marsh turtle highly specialized, would seem in all probability to furnish a forcible defense for the theory of the Antarctic continent. But more than this the results of renewed investigation of the Argentine beds by the members of the Princeton University of North America have recently resulted in collections which, we are informed, seem likely to surpass all precedent in their bearings upon our current ideas, not the least remarkable preliminary announcement being the statement that there occurs fossil a mole indistinguishable, so far as is known, from the golden mole (*Chrysochloris*) of South Africa.

Before I dismiss this fascinating subject let me disarm the notion, which may have arisen, that the paleontological work of the Old World is done. Far from it! Even our American cousins have to come to us for important fossil forms as, for example, the genus *Pliohyrax* of Samos and the Egyptian desert, while among the rodents and smaller carnivores there are large collections in our national museum waiting to be worked over afresh.

If one part of the globe more than another is just now the center of interest concerning its vertebrate remains, it is the Egyptian desert. Here there have recently been found the bones of a huge cetacean associated, as in South America, with those of a giant snake, one of the longest known, since it must have reached a length of 30 feet. There also occur the remains of other snakes, of chelonians of remarkable adaptive type, of crocodilians, fishes, and other animals. Interest, however, is greatest concerning the Mammalia, which for novelty are quite up to the American standard, as with an upper and a lower jaw of an anomalous creature, concerning which we can only at present remark that it may be a marsupial, or more probably a carnivore, which has taken on the rodent type in a manner peculiarly its own.

Important beyond this, however, are a series of Eocene forms which more than fill a long-standing gap, viz, that of the ancestors of the elephants and mastodons, which hitherto stopped short in the Middle Miocene of both Old and New Worlds. As represented by the genus *Mæritherium*, they have three incisors above and two below, of which the second is in each case converted into a short but massive tusk. An upper canine is present, and in both upper and lower jaws a series of six cheek teeth, distinct and bunodont in type. In the allied *Barytherium*, of which a large part of the skeleton is known, the upper incisors were presumably reduced to two, the tusks enlarged, with resemblances in detail to the Dinoceratan type.

So far as these remains are known, they appear to present in their combined characters all that the most ardent evolutionist could desire. There are with them Mastodons, which simplify our knowledge of this group, and among the last-discovered remains Sirenians, which, in presenting a certain similarity to the afore-mentioned Mæritherium, strengthen the belief in the proboscidian relationships of these aquatic forms. Finally, and perhaps most noticeable of all, there is the genus *Arsinoitherium*, a heavy brute with an olfactory vacuity which outrivals that of *Grypotherium* itself, and is surmounted by a monstrous fronto-nasal horn, swollen and bifid, for which the most formidable among the Titanotheres might yearn in vain. There is an occiput to match! The suggestion that this extraordinary beast has relationships with the Rhinoceridæ is absurd, since its tooth pattern alone inverts the order of this type. That it is proboscidian may be nearer the mark, and if so it shows once more how subtle were the mammals of the past. Great as is this result much remains to be done or done again, if only from the fact that in seeking to determine homologies our American brethren, in the opinion of some of us, have placed too much reliance on a so-called tritubercular theory of tooth genesis, of which we can not admit the proof. How, we would ask, is it conceivable that a transversely ridged molar of the *Diprotodon* type can be of tritubercular origin?

Sufficient for the moment of paleontological advance, except to remark that the zoologist who neglects this branch of morphology misses the one leavening influence; neglects the court on whose ruling arguments deduced from embryological data alone must either stand or fall. We may form our own conclusions from facts of the order before us, but it is when we find their influence on the master mind prompting to action, like that of Huxley with his mighty memoir of 1880, in which he revised our subclass terms, that we appreciate them to the full.

With this consideration we pass to the living forms, and I have only time in dealing with these to comment on advance which affects our broadest conceptions and classifications of the past.

To commence with the Mammalia, we now know that the mammary gland when first it appears is in all forms tubular, and that this type is no longer distinctive of the Monotremata alone. We know, too, that the intranarial position of the epiglottis when at rest, long known for certain forms, is a distinction of the class. It explains the presence of the velum palatinum by its association with the glottis for the restriction of the respiratory passage, the connection being lost in man alone under specialization of the organ of the voice.

Similarly the doubly ossified condition of the coracoid may now be held diagnostic, for it is known that the epicoracoidal element, originally thought to characterize the monotremes alone, is always present, and that reduction to a varying degree characterizes the metacoracoid, which retires, as in man, as the so-called coracoid epiphysis.

Our conceptions of the interrelationships of the Marsupialia and Placentalia have, during the period we are considering, been delimited beyond expectation by the discovery of an allantoic placenta in a polyprotodont marsupial in place of the vitelline, present in its allies. When it is remembered that in the formation of the placenta of the rabbit and a bat there is realized a provisional vitelline stage, it is tempting to suggest that the evidence for the direct relationship of the two mammalian subclasses first named overlaps (there being a placental marsupial on one hand, a marsupial placental on the other), much as we have come to regard Archæopteryx as an avian reptile, the Odontornithes as reptilian birds. These facts, moreover, prove that the type of placenta inherited by the Placentalia must have been discoidal, and that from that all others were derived.

Equally important concerning our knowledge of the Marsupialia is the discovery, first made clear by Professor Symington, of this college, that Owen was correct in denying them a corpus callosum. How Owen arrived at this conclusion it is difficult to conceive, but in these later days the history of discovery is largely that of method, and it is by the employment of chrome silver, methylene blue, and other reagents, which in differentiating the fiber tracts enable us to delimit their course, that this conclusion has been proved. By the corpus callosum we now understand a series of neopallial fibers which transect the alveus and are present only in the Placentalia.

There is no department of mammalogy in which recent work has been more luminous than this which concerns the brain, and, to mention but one result, it may be said that in the renewed study of the commissures there has been found a fiber tract characteristic of the Diprotodontia alone, so situated as to prove that they and the Placentalia must have specialized on diverse lines from a polyprotodont stock. Interesting this the more, since the phalangers and kangaroos are known to be polyprotodont when young. And when we add the discovery that in the detailed relationship of its commissures the brain

of the Elephant Shrew, a lowly insectivore, alone among that of all Placentalia known realizes the marsupial state, as does its accessory organ of smell, we have to admit the discovary of annectant conditions just where they should occur.

The morphological method is sound!

The master hand which has given us this result has also reinvestigated the Lemurs. From an exhaustive study of the brain or its cast of all species of the order, living and extinct, there has come the proof that the distinctive characters of the lemuroid brain are intelligible only on a knowledge of the pithecoid type; that its structural simplicity in the so-called lower lemurs is due to retrogressive change, in some species proved to be ontogenetic, and that the Tarsier, recently claimed to be an insectivore, is a lemur of lemurs. It is impossible to overestimate the importance of this conclusion, which receives confirmation in recent paleontological work; and there is demanded a reinvestigation of those early described Tertiary fossil forms placed on the Ungulo-lemuroid border line, as also a reconsideration of current views on the evolution of the primates and of man.

In dismissing the Mammalia we recall the capture during the period we review of three new genera, a fourth, the so-called *Neomylodon*, having proved by its skull to be *Grypotherium darwinii*, already known. The African Okapi, an object of sensation beyond its deserts, has found its place at last. To have been dubbed a donkey, a zebra, and a primitive hornless giraffe is distinction indeed; and we can not refrain from contrasting the nonsensical statement that its discovery is "the most important since Archæopteryx" with the truth that it is a giraffine, horned for both sexes; annectant between two groups well known. As a discovery it does not compare with that of the Mole-marsupial, and it falls into insignificance beside that of the South American diprotodont *Cœnolestes*, the survivor of a family which there flourished in Middle Tertiary times.

Passing to birds and reptiles, it will be convenient to consider them together. A knowledge of their anatomy has extended on all hands, and in respect to nothing more instructively than their organs of respiration. Surprise must be expressed at the discovery in the chelonian of a mode of advancing complication of the lung suggestive of that of birds. On looking into this I find that Huxley, who rationalized our knowledge of the avian lung and its sacs, was aware of the fact that in our common water tortoise (*Emys orbicularis*) the lung is sharply differentiated along the bronchial line into a postero-dorsal more cellular mass, an antero-ventral more saccular, of which the posterior vesicle, in its extension and bronchial relationships, strangely simulates the so-called abdominal sac of birds. He had already instituted comparison with the crocodiles, and was clearly coming to the conclusion that the arrangement in the bird is but the

result of extreme specialization of a type common to all Sauropsida with a "cellular" lung. The respiratory process in the bird may be defined as transpulmonary, and it is an interesting coincidence that as I write there comes to hand a memoir supporting Huxley's conclusion and establishing the fact that there is a fundamental principle underlying the development and primary differentiation of all types of vertebrate lung.

The discovery of the Odontornithes in the American Cretaceous is so well known that it is but necessary to remark that nine genera and some twenty species are recognized. To *Archæopteryx* I shall return. Before dismissing the Chelonia, however, it must be pointed out that paleontology has definitely clenched their supposed relationship to the Plesiosaurs. Of all recent paleontological collections there are none which, for care in collecting and skill in mounting, surpass the reptilian remains from the English Jurassic (Oxford clay) now public in our national museum. The Plesiosaurs of this series must be seen to be appreciated, and nothing short of a merciful Providence can have interposed to insure the generic name *Cryptocleidus*, which one of them has received, since the hiding of the clavicle, its diagnostic character, is an accomplished fact. It is due to secondary displacement under the approximation in the middle line of a pair of proscapular lobes, present in the Plesiosauria and Chelonia alone, and until the advent of this discovery misinterpreted. Taken in conjunction with other characters of little less importance, conspicuously those of the plastron and pelvis, this decides the question of affinity, and proves the Chelonia to have had a lowly ancestry, as has generally been maintained.

Recent research has fully recorded the facts of development of the rare New Zealand reptile *Sphenodon*, and it has more than justified the conclusion that it is the sole survivor of an originally extensive and primitive group, the Rhynchocephalia, as now understood. To confine our attention to its skeleton, as that portion of its body which can alone be compared with both the living and extinct, it may be said that positive proof has been for the first time obtained that the developing vertebral body of the terrestrial vertebrata passes through a paired cartilaginous stage and that in its details the later development of this body is most nearly identical with that of the lower Batrachia. There has long been a consensus of opinion that the forward extension of the pterygoids to meet the vomers in the middle line, known hitherto in this animal and the crocodiles alone, is for the terrestrial vertebrata a primitive character, and proof of this has been obtained by its presence in all the Rhynchocephalia known. The same condition has also been found to exist in the Plesiosaurs, the Ichthyosaurs, the Pterodactyles, the Dicynodontia, the Dinosaurs, and with modification in some chelonians. It has, moreover, been found in living birds;

a most welcome fact, since *Archæopteryx*, in the possession of a plastron, carries the avian type a stage lower than the Dinosaurs. It is pertinent here to remark that, inasmuch as in those Dinosaurs (e. g., *Compsognathus*) in which the characters of the hind limbs are most nearly avian, the pelvis, in respect to its pubis, is at the antipodes of that of all known birds, and the fore limb is shortened in excess of that of *Archæopteryx* itself, the long supposed dinosaurian ancestry for birds must be held in abeyance.

Passing through the Rhynchocephalia to the Batrachia we have to countenance progress most definite in its results. The skull, the limbs and their girdles are chiefly concerned, and this in a very remarkable way.

In the year 1881 there was made known by Professor Froriep, of Tübingen, the discovery that the hypoglossus nerve of the embryo mammal is possessed of dorsal ganglionated roots. Again and again have I heard Huxley insist on the fact that the ventral roots of this nerve are serial with the spinal set, but never did he suspect the rest. It is, however, a most intensely interesting fact that, whereas by a Huxleian triumph the vertebral theory of the skull was overthrown, in these later Huxleian days the proof of the incorporation of a portion of the vertebral region of the trunk into the mammalian occiput should have marked the succeeding epoch in advance. The existence of twelve pairs of cranial nerves which all the Amniota possess involves them in this change, and the fact that in all Batrachia there are but ten, enables us to draw a hard-and-fast line between batrachian and amniote series.

It may be urged as an objection that since we have long been familiar with a fusion of vertabræ and skull in various piscine forms, the force of this distinction is weakened. But this can not be, since in respect to the investing sheaths and processes of development which lie at the root of the genesis of the vertebral skeleton, the fishes stand distinct from the Batrachia and Amniota, which are agreed. So forcible is this consideration that it behooves us to express it in words, and I have elsewhere proposed to discriminate between the series of terrestrial vertebrate as archæ craniate and syncraniate.

Similarly, there is no proof that any batrachian, living or extinct (and in this I include the Stegocephala as a whole), possesses a costal sternum. So far as their development is known, the cartilages in these animals called "sternal" are either coracoidal or sui generis. The costal sternum, like the syncraniate skull, is distinctive of the Amniota alone. Had the Stegocephala possessed it even in cartilage, there is reason to think it might have been preserved, as it has been in the collossal Mososaur *Tylosaurus* of the American Cretaceous. When to this it is added that whereas, in the presence of a costal sternum, the mechanism of inflation of the lung involves the body wall, in its absence

it mainly involves the mouth (as in all fishes and batrachians), the hard and sharp line between the Batrachia and Amniota may be expressed by the formula that the former are archæcraniate and stomatophysous, the latter syncraniate and somatophysous.

There are allied topics which might be considered did our time permit, but one certain outcome of this is that there is an end to the notion of a batrachian ancestry for the Mammalia. And when, on this basis, we sum up the characters demanded of the stock from which the Mammalia have been derived, we find them to be precisely those occurring outside the Mammalia in the Anomodont reptiles alone. Beyond the sternum and skull the chief characters are the possession of short and equal pentadactyle limbs, with never more than three phalanges to a digit, a complete fibula and clavicle, a doubly ossified coracoid, a heterodont dentition—a combination which, wholly or in part, we now associate with the Permian genera *Procolophon*, *Pariasaurus*, and others which might be named, the discovery of which constitutes one of the morphological triumphs of our time.

Beyond this, it may be added concerning the Batrachia, that among living pedate forms the anura have alone retained the pentadactyle state and the complete maxillo-jugal arch, and that the Eastern *Tylototriton*, in the possession of the latter, becomes the least modified urodele extant. These facts lead to the extraordinary conclusion that the living Urodela, while of general lowly organization, are one and all aberrant; and it is not the least important sequel to this that, despite their total loss of limbs, the Apoda, in the retention of the dermal armor and other features which might be stated are the most primitive Batrachia that exist.

The batrachian phalangeal formula 22343 was until quite recently a difficulty in the determination of the precise zoological position of the class, but it has now been overcome by the discovery of a *Keraterpeton* in the Irish carboniferous having three phalanges on the second digit of both fore and hind limbs, and by that in the Permian of Saxony of a most remarkable creature, *Sclerocephalus*, which, if rightly referred to the Stegocephala, had a head encased, as its name implies, in an armature like that of a fish, and the phalangeal formula of a reptile, 23454.

Passing from the batrachia to the fishes, we have still to admit a gap, since an interminable discussion on figures and fins has not narrowed it in the least. In compensation for this, however, we have to record within the fish series itself progress greater, perhaps, than with the higher groups. Certainly is this the case if, as to bulk, the literature in systematic sand palæontology be alone taken into account.

Of the Dipnoi our knowledge is fast becoming complete. We know that *Lepidosiren* forms a burrow, and in consideration of a former monstrous proposal to regard this animal, with its 56 pairs of ribs,

and *Protopterus*, with its 30 to 35, as varieties of a species, it is the more interesting to find that the Congo has lately yielded a *Protopterus* (*P. Dolloi*) with the lepidosiren rib formula, viz, 54 pairs.

As a foremost result of American paleontological research we have to record the occurrence, in the Devonian of Ohio, of a series of colossal fishes known as the Arthrodira, the supposed dipnoan affinities of which are still a matter of doubt.

We have evidence that the osseous skeleton in a plate-like form first appeared as a protection for the eye of a primitive shark, and coming to recent forms having special bearings on the teachings of the rocks, we have to acknowledge the capture in the Japanese seas of a couple of ancient sharks, of which one (*Cladoselachus*), since observed to have a distribution extending to the far north, is a survivor from Devonian times; the other (*Mitsukurina*), a genus whose grotesqueness leaves no doubt of its identity with the Cretaceous lamnoid *Scapanorhynchus*. In the elucidation of the Sturiones, and the determination of their affinities with the ancient Palæoniscidæ, a master stroke has been achieved. In the Old Red genus *Palæospondylus* we have become familiar with an unmistakable marsipobranch, possessing, as do certain living fishes, a notochord, annulated, but not vertebrated in the strict sense of the term. The climax in Ichthyopalæontology, however, has been reached in the discovery of Silurian forms, which there is every reason to believe explain, in an unexpected way, the hitherto anomalous Pteras- and Cephalaspidians, by involving them in a community of ancestry with the primitive Elasmobranchs. The genera *Thelodus*, *Drepanaspis*, *Ateleaspis*, and *Lanarkia*, chief among these annectant and ancestral forms, are among the most remarkable vetebrate fossils known.

Passing to the Recent fishes alone, the discovery which must take precedence is that of the mode of origin of the skeletogenous tissue of their vertebral column. The fishes, unlike all the higher Vertebrata, have, when young, a notochord invested in a double sheath, there being an inner chordal sheath, an outer cuticular, which latter is alone present in all the higher groups. The skeletogenous cells, by whose activity the cartilaginous vertebral skeleton is formed, arise outside these sheaths; but whereas when proliferating they in one series remain outside, they in the other, by the rupture of the cuticular sheath, invade the chordal. This distinction enables us to discriminate between a *Chordal series*, which embraces the Chimæroids, Elasmobranchs, and Dipnoi, and a *Perichordal*, consisting of the Teleosts, Ganoids, and Cyclostomes.

In consideration of the enormity of the structural gap between the Cyclostomes and the higher Vertebrata this is an extraordinary result. For be it remembered that, in addition to their well-known characters,

the lampreys and hags (1) in the total absence of paired fins; (2) in the presence of branchiæ, ordinarily 7 in number, 14 in *Bdellostoma polytrema*, numerically variable in individuals of certain species between 6 and 14, and doubtfully asserted in the young of one to be originally 35; and (3) in the carrying up of their oral hypopophysis by the nasal organ, whereby it perforates the cranium from above, as contrasted with all the higher Vertebrata, in which, carried in with the mouth sac, it perforates it from beneath, exhibit morphological characters of an extraordinary kind. And if we are to express these characters in terms we may distinguish the Cyclostomes as *apterygial* and *epicraniate*, the higher Vertebrata as *hypocraniate*.[a] But this, notwithstanding the aforementioned subdivision of the Pisces into two series, which would associate the teleosts and ganoids with the cyclostomes, as distinct from the rest, receives support from recent study of the head-kidney by a Japanese, who seeks to show that the organ so called in the Elasmobranchs is of a late-formed type peculiar to itself, and it is also in agreement with one set of conclusions previously deduced from the study of the reproductive organs.

To deal further with the fishes is impossible in this address, except to remark that recent discovery in the Gambia, that the young of the Teleostean genera *Heterotis* and *Gymnarchus* bear filamentous external gills, renders significant beyond expectation the alleged presence of these among the loaches, and shows that adaptive organs of this type are valueless as criteria of affinity.

In paleontology, as in recent anatomy, our records of detail have increased beyond precedent, often but to show how deficient in knowledge we are, how contradictory are our theories and facts.

In dismissing the fishes, I wish to comment upon our accepted terms of orientation. To speak of the median fins as dorsal, caudal, and anal, of the pelvic as ventral, and of the pectoral in its varying degrees of forward translocation as abdominal or thoracic, though a convention of the past, is to-day inaccurate and absurd. I question if the time has not come at which the terms thoracic (pulmocardiac) and abdominal are intolerable, as expressing either the subdivisions of the body cavity or anything else outside the Mammalia, which alone possess a diaphragm. Even in the birds, to grant the utmost, the subdivision of the cœlom, if accurately described, must be into pulmonary, hyper-pulmonary, and cardio-abdominal chambers, while with the reptiles the modes of subdivision are so complex that a special terminology is necessary for each of the several types extant.

[a] It is an interesting circumstance, if their "ciliated sac" is rightly homologized, that *Amphioxus* and the Tunicata present a corresponding dissimilarity, allowance being made for the fact that in *Botryllus*, *Goodsiria*, and *Polycarpa* the sac overlies the ganglion. It is pertinent here to recall the ammocœte-like condition of the "endostyle" in *Oikopleura flabellum*.

In the fishes, where the pericardium is alone shut off, the retention of the mammalian terms but hampers progress. This was indeed felt by Duméril when, in 1865, he attempted a revisionary scheme. Since, however, one less fantastic than his seems desirable, I would propose that for the future the "anal" fin be termed ventral, the "ventral" pelvic, and that for the several positions of the pelvic, that immediately in front of the vent, primitive and embryonic (which is the position for the Elasmobranchs, Sturiones, Lower Siluroids, and all the higher Vertebrata), be termed proctal, the so-called "abdominal" pro-proctal, the so-called "thoracic" jugular (in that it denotes association with the area of the "collar bone"), and the so-called "jugular" mental. The necessity for this becomes the more desirable now that it is known that a group of Cretaceous fishes (the Ctenothrissidæ), hitherto regarded as Berycoids, are in reality of clupeoid affinity, despite the fact that at this early geologic period they had translocated their pelvic fin into the jugular ("thoracic") position.

The sum of our knowledge acquired during the last twenty-eight years proves to us that among the bony fishes the structural combination which would give us a premaxillo-maxillary gape dentigerous throughout, a proctal pelvic fin, a heart with conal valves, would be the lowest and most primitive. Inasmuch as this character of the heart, so far as at present known, exists only among the Clupesoces (pikes and herrings and their immediate allies), these must be regarded as lowly forms, wherefore it follows that the possession of but a single dorsal fin is not, as might appear, a necessary index of a highly modified state.

Before I dismiss the vertebrates, a word or two upon a recent result of morphological inquiry which concerns them as a whole. I refer to the development of the skull. Up to 1878 it was everywhere thought and taught that the cartilaginous skull was a compound of paired elements, known as the trabeculæ cranii and parachordals, and that the former contributed the cranial wall. Huxley, in 1874, from the study of the cranial nerves of fishes, had reiterated the suggestion he made in 1864, when dealing with the skull alone, that the trabeculæ might be a pair of præ-oral visceral arches, serial with those which support the mouth and carry the gills. The next step lay with the sturgeon, in which, in 1878, it was found that the cranial wall is originally distinct. And later, when the facts were more fully studied in sharks, batrachians, reptiles, and birds it became evident that the trabeculæ, though ultimately associated with the cranial wall, take no share in its formation, and that when first they appear they are disposed at right angles to the parachordals and the axis serially with the visceral arches behind. Huxley was right, and although this consideration by no means exhausts the category of independent cartilages now known to contribute to the formation of the skull, it proves

that the cartilaginous cranium, like the bony one which in the higher vertebrate forms replaces it, is in its essence compound.

I now pass to the invertebrata. Of the Oligochæta and Leeches I have spoken, and we may next consider the Arthropods. Of the Insecta our knowledge has gained precision by the conclusion that the primitive number of their Malpighian tubes is six, and by the study of development of these in the American cockroach *Doryphora*, which has rendered it probable they may be modified nephridia, carried in as are those of some oligochætes with the proctodeal invagination. An apparent cervical placenta has been discovered in the orthopteran *Hemimerus*, which would seem to suggest homology with the so-called "trophic vesicle" of the Peripatoids, as exemplified by *P. Novæ-Britannicæ*. In this same orthopteran there have been recognized, in secondary proximity to the "lingua," reduced maxillulæ, which, fully developed and interposed between the mandible and first maxilla, in *Japyx*, *Machilis*, *Forficula*, and the *Ephemera* larva, give us a fifth constituent for the insectan head. And when it is found that all the abdominal segments of the common cockroach, when young, are said to bear appendages, of which the cerci are the hindermost, we have a series of facts which revolutionize our ideas. Little less striking is the discovery that in the caterpillar of the bombycine genera *Lagoa* and *Chrysopyga* seven pairs of pro-legs occur.

The fuller study of the apertures of the tracheate body has resulted in the discovery that the Chilopoda are more nearly related to the Hexapoda than to the Diplopods; wherefore it is proposed to reclassify the Tracheata, in accordance with the position of the genital orifice, into *Pro-* and *Opistho-gonata*. In a word the "Myriapoda," if a natural group, are diphyletic.

Our knowledge of the Peripatoids (*Arthropoda malacopoda*) has increased in all that concerns distribution and structure. They are now known, for example, from Africa, the West Indies, Australia, and New Zealand, and for examples from the two latter localities and Tasmania the generic name *Ooperipatus* has but lately been proposed, to include three species, characterized by the possession of an ovipositor, of which two have been observed to lay eggs.

Work upon the Crustacea in our own land, notorious for the tendencies of some of its devotees in their stickling for priority, has within the last twelve years advanced beyond all expectation. Much of our literature has been systematized, and an enormous increase in our knowledge of new forms has to be admitted, thanks to memoirs such as those of the "Investigator," "Naples Zoological Station," and others which might be named; while in the discovery and successful monographing, in the intervals of six years' labor at other groups, of a new family of minute Copepods (the Choniostomatidæ), parasitic on the Malacostraca, embracing forty-three species, difficult to find, we have an almost unique achievement. The hand which gave us this

has also provided a report which embraces the description of a nauplius of exceptional type, which, by a process of reasoning by elimination, masterly in its method, has been "run to ground" as in every degree of probability the larva of Darwin's apodal barnacle *Protolepas bivincta*, of which only the original specimen is known.

There is but one other crustacean record equal in rank with this, viz, the discovery of the genus *Anaspides*. Originally obtained from a fresh-water pool on Mount Wellington, Tasmania, at 4,000 feet, it has since been found in two other localities. It is unique among all living forms, in combining within itself characters of at least three distinct suborders of "prawns," for with a schizopod body it combines the double epipodial lamellæ of an amphipod, the head of a decapod (pedunculated eyes and antennulary statocysts) apart from characters peculiarly its own. There is reason to believe that the nearest living ally to this remarkable creature is a small eyeless species (*Bathynella natana*) obtained from a Bohemian well; and if its presumed relationships to the Palæozoic "pod-shrimps" be correct, this heterogeneous assemblage may perhaps be the representatives of a group of primitive Malacostraca, through which, by structural divergence, the establishment of the higher crustacean suborders may have come about.

It is pertinent to this to note that work upon cave dwelling and terrestrial forms, upon "well shrimps" and the like, has produced important results. And interesting indeed is the recent discovery of three species, living at 800 to 900 feet above sea level, in Gippsland, one an amphipod, two of them isopods, which, though surface dwellers, are all blind. While they prove to be species of genera normally eyed, they in their characters agree with well-known American forms; and the bleaching of their bodies and atrophy of their eyes proclaim them the descendants of cave-dwelling or subterranean ancestors, among whom the atrophy took place.

Huxley in 1880 rationalized our treatment of the higher Crustacea, by devising a classification by gills, expressive of the relationships of these to the limb-bases, interarticular membranes, and body wall. Hardly had his influence taken effect when, by work extending over the years 1886 to 1893, in the study of Penæus, the Phyllopods, Ostracods, and other forms, evidence had been accumulating to show that the crustacean appendage, even to the mandible itself, has primarily a basal constituent (protopodite) of three segments; that the branchiæ one and all are originally appendicular in origin; and that the numerical reduction of the basal (protopoditic) segments to two, with the assumption of a nonappendicular relationship by the gills, is due to coalescence of parts, with or without suppression. The evidence for this epoch-making conclusion, which simplifies our conceptions and brings contradictory data into line, is as irresistible as it is important, and there has been nothing finer in the whole history of

crustacean morphology. With it, the attempt to explain the supposed anomalous characters of the antennule by appeal to embryology goes to the wall; and, taking a deep breath, we view the Crustacea in a new light.

There remains for brief consideration one carcinological discovery second to none which bear on the significance of larval forms. It is that of the trilobite *Triarthrus Becki*, obtained in abundance from the Lower Silurian near New York, with all its limbs preserved. In the simplicity of its segmentation and the biramous condition of its limbs it is primitive to a degree. Chief among its characters are the total absence of jaws in the strict sense of the term, and the fact that of its three anterior pairs of appendages the third is certainly and the second is apparently biramous, the first uniramous and antenniform. In this we have a combination of characters known only in the nauplius larva among all living crustacean forms; and the conclusion that the adult trilobite, like that of the Euphausiacea, Sergestidæ Penæidæ, the Ostracods, and Cirripedes of to-day, was derived by direct expansion of the nauplius larva can hardly be doubted. Much yet remains to be done with the study of the Triarthrus limbs; and the suggestion of a foliaceous condition by those of the pygidium, which are the youngest, is a remarkable fact, the meaning of which the future must decide. We should expect the condition to be a provisional one, since while we admit the primitive nature of the phyllopods as an order, we can not regard the foliation of their appendages as anything but a specialization. Be this as it may, the structural community between the nauplius larva and the trilobite is now proved; and when we add that in the yolk-bearing higher Crustacean types (e. g., *Astacus*) a perceptible halt in the development may be observed at the three-limb-bearing stage; that in *Mysis* the vitelline membrane is shed but to make way for a nauplius cuticle; and that the median nauplius eye has long been found sessile on the adult brain of representative members of the higher crustacean groups, up to the lobster itself, our belief in the ancestral significance of the nauplius larval form is established beyond doubt.

The thought of the nauplius suggests other larval forms. The gastrula is no longer accepted without reserve; the claims of the blastula, planula, parenchymella, not to say the plakula, have all to be borne in mind. It is of the Trochophore, however, as familiar as the nauplius, that I would rather speak, as influenced by recent research. It is supposed to be primitive for the molluscs and chætopod worms at least; and various attempts have been made to bolster it up, and to show that if we allow for adaptive change, its characters, well known, are constant within the limits of its simpler forms.

It is now more than forty years ago that the late Lacaze-Duthiers described for *Dentalium* a larval stage, characterized by the posses-

sion of recurrently ciliated zones, which by reduction, with union and translocation forwards, give rise to the trochal lobe. It is now known that in the American pelecypod *Yoldia limatula* a similar stage is found, in which a "test" of five rows of ciliated cells is present; and of the young of *Dondersia banyulensis* the like is true. But whereas in the *Yoldia* the ciliated sac is ultimately shed, in the Myzomenian the escape of the embryo is accompanied by rupture, which liberates the anterior series of ciliated zones in a manner strongly suggestive of forward concentration, leaving the posterior circlet with its cilia attached.

This "test" has also been seen in two species of *Nucula*, and pending fuller inquiry into the Myzomenian and a reinvestigation of Dentalium, I would suggest that this recurrently ciliated sac is representative of a larval stage antecedent to the trochophore, for which the term protrochal may suffice. This term has indeed been already applied to a larva of certain Polychæta, which might well represent a modification of that for which I am arguing; and quite recently it appears to have been observed near Ceylon for a species of the genus *Marphysa*.

The discovery of this larva in *Dondersia* was accompanied by that of a later-formed series of dorsal spicular plates, which for once and for all, in realizing a chitonid stage, demolish the heresy of the "Solenogastres," mischievous as suggesting an affinity with the worms. Like that of the supposed cephalopod affinities of the so-called "Pteropods," it must be ignored as an error of the past.

Returning to the protrochal stage, whatever the future may reveal concerning it, by bringing together the Lamellibranchiata, Scaphopoda, and Polyplacophora, it associates in one natural series all the bilaterally symmetrical Mollusca except the cephalopods. In doing this, it deals the death blow to the supposed Rhipidoglossan affinity of the Lamellibranchiata; and in support of this conclusion I would point out that the recently discovered eyes of the mytilids are in the position of those of the embryo *Chiton*, and that just as *Dentalium*, in the formation of its mantle, passes through a lamellibranchiate stage, so are there lamellibranchs in number in which a tubular investment is found.

This protrochal larva has an important part to play. It may very possibly explain phenomena such as the compound nature of the trochal lobe of the limpet, the presence of a post-oral ciliated band in the larva of the shipworm, and of a præ-anal one in that of various molluscan forms. In view of it, we must hesitate before we fully accept the belief in the ancestral significance of the trochophore. And it is certain that an idea, at one time entertained, that the Rotifer (*Trochosphæra*), which so closely resembles it as to bear its name, is its persistent representative, is wrong, since this is now known to be but the female of a species having a very ordinary male.

Through the Rhipidoglossa we pass to the Gastropods, which are one and all asymmetrical, for even *Fissurella*, *Patella*, and *Doris*, when young, develop a spiral shell; while Huxley in 1877 had observed that the shell of *Aplysia*, in its asymmetry, betrays its spiral source.

The notion, which until recently prevailed, that among these gastropods the nontwisted or so-called euthyneurous condition of the visceral nerve cords, as exemplified by the Opisthobranchs, is a direct derivative of that of the Chitons, has been proved to be erroneous, since the nerves in *Actæon* and *Chilina*, like those of the prosobranchs, are twisted or streptoneurous. And as to the torsion of the gastropod body, recent research, in which one of my pupils has played a part, involving the discovery of paired reno-pericardial apertures in *Haliotis*, *Patella*, and *Trochus*, has resulted in proof that the dextral torsion which leads to the monotocardiac condition, does not uniformly affect all organs lying primitively to the left of the rectum, as we have been taught; since, concerning the renal organs, it is the primitively (pretorsional) left one which remains as the functional kidney, its ostium as the genital aperture. Nor is the primitively right kidney necessarily lost, for while its ostium remains as the renal orifice, its body, by modification and reduction, may become an appendage of the functional kidney, the so-called nephridial gland. And we now know there are cases of sinistral torsion of the visceral hump, in which the order of suppression of the organs is not reversed, the arrangement being one of adaptation of a dextral organization to a sinistral shell.

Though thus specialized and asymmetrical as a group, the gastropods are yet plastic to an unexpected degree. Madagascar has yielded a Physa (*P. lamellata*) with a neomorphic gill, a character shared by species of *Planorbis* (*P. corneus* and *P. marginatus*), and an *Ancylus* in which the lung sac is suppressed; while St. Thomas Island has given us a snail (*Thyrophorella thomensis*), the peristome of whose shell is produced into a protective lid.

In paleontology, history records the fact that in 1864 Huxley observed that the genus *Belemnites* appears to have borne but six free arms, a startling discovery which lay dormant till the present year. And the recent study of the fauna of the great African lakes, in bringing to light the existence of a halolimnic molluscan series in Lake Tanganyika, has opened up new possibilities concerning the paleontological resources of enormous aqueous deposits, recently discovered in the interior, and has entirely changed our geological conceptions of the nature of equatorial Africa.

Time prevents my dealing with other groups, and it must suffice to say that with those I have not considered substantial work has been done. From what has been said, it is natural to expect that in some direction or another so vast an accumulation of facts must have extended the Darwinian teaching; and it is now quite clear that this

has been the case with the two post-Darwinian principles known as "Substitution" and Isomorphism or "Convergence."

The former may be exemplified by nothing better than the case of the Rays and Skates, in which, under the usurpation of the propelling function of the tail by the expanded pectoral fins, the tail, free to modify, becomes in one species a lengthy whiplash; in another a vestigial stump; in others, by the development of powerful spines, a formidable organ of defense. In both the Rays and certain other fishes subject to the working of this law, modification goes further still, in the appearance of electric organs in remotely related genera and species, by specialization of the muscular system of the trunk or tail, or, as in the case of *Malapterurus*, of "tegumental glands." In this we have a difficulty admitted by Darwin himself, which now becomes clear and intelligible, since there is nothing new. There has simply come about the conversion, in one case of the energy of muscular contraction, in the other of glandular secretion, into that of electrical discharge, with accompanying structural change. The blind locust (*Pachyramina fuscifer*) of the New Zealand limestone caves presents an allied case, since here, under the reduction of the eye, the antennæ, elongated to a remarkable degree, have become the more efficiently tactile; and it is an interesting question whether this principle may not explain the attenuation of the limbs in the recently discovered American proteoid (*Typhlomolga rathburni*) of the Texan subterranean waters.

And as to isomorphism, by which we mean the assumption of a similar structural state by members of diverse or independent groups, I would recall the case of the Eocene Creodont *Patriofelis* and the Seals, and that of the Myriapods to which I have already alluded, and would cite that of the Dinosaurs and Birds, heterodox though it may appear, for reasons I have given.

As our knowledge increases, there is every reason to believe that, in the nonappreciation of these principles in the past, not a few of our classifications are wrong. We have even had our bogies, as, for example, the so-called Physemaria, which deceived the very elect; and before I close I wish to deal briefly with a question of serious doubt which these considerations suggest.

It is that of the position in the zoological series of the Limuloids, popularly termed the King crabs. These creatures, best known from the opposite shores of the northern Pacific, but found in the oriental seas as well as far south as Torres Strait, have been since 1829 the subject of a difference of opinion as to their zoological position and affinities. Within the last twenty years there have been three determined advances upon them, and of these the third and most recent may be first discussed. It has for its object the attempt to prove that they are intimately associated with the cephalaspidian and other

shield-bearing fishes of the Devonian and Silurian epochs, and that through them they are ancestral to the Vertebrata. The latest phase of this idea is based on the supposed existence in a *Cephalaspis* of a series of twenty-five to thirty lateral appendages of arthropod type. When, however, it is found that the would-be limbs are but the edges of body scutes misinterpreted, suspicion is aroused; and when, working back from this, an earlier attempt reveals the fact that the author, compelled to find trabeculæ, in order to force a presupposed comparison between the architecture of the Cephalaspidian head shield and the Limulus' prosomal hood, resorts to a comparison between the structure of the former in general and that of the cornu of the latter, with details which on the piscine side are not to date, the argument must be condemned. It violates the first principles of comparative morphology, and is revolting to common sense; and as to the fishes concerned, we know that they have nothing whatever to do with the Limuloids, for we have already seen that, with their allies the Pteraspidiæ, they are a lateral branch of the ancestral piscine stem.

The second advance upon the King crabs has very much in common with the first. It has engrossed the attention of an eminent physiologist for the last six or seven years, and by him it was in detail set before Section I at our meeting of 1896. Suffice it to say that it specially aims at establishing a structural community between the king crabs and certain vertebrates, favorable to the conviction that the vertebrata have had an arthropod ancestry. When we critically survey the appalling accumulation of words begotten of this task, it is sufficient to consider its opening and closing phases. At the outset, under the conclusion that the vertebrate nervous axis is the metamorphosed alimentary canal of the arthropod ancestor, the necessity for finding a digestive gland is mainly met by homologizing the so-called liver of the arthropod with the cellular arachnoid of the larval lamprey, in violation of the first principles of comparative histology. At the close we find ingenious attempts to homologize nerve tracts and commissures related to the organs of sense, such as are invariably present wherever such organs occur. Sufficient this to show that the comparison, in respect to its leading features, is in the opening case strained to an unnatural degree, in the closing case no comparison at all. Finding, as we do, that the rest of the work is on a par with this, we are compelled to reject the main conclusion as unnatural and unsound; and when we seek the explanation of this remarkable course of action, we are forced to believe that it lies in the failure to understand the nature of the morphological method. For the proper pursuit of comparative morphology, it is not sufficient that any two organisms chosen here and there should be compared, with total disregard of even elementary principles. Comparison should be first close and with nearly related forms, passing later into larger groups, with the progressive

elimination of those characters which are found to be least constant. And necessary is it, above all things, that in instituting comparison it should be first ascertained what it is that constitutes a crustacean, a marsipobranch, a cyclostome, and so on for the rest. We have tried to accept this theory, fascinated both by the arguments employed and by the idea itself, which for ingenuity it would be difficult to beat, but we can not; and we dismiss it as misleading, as a fallacy, begotten of a misconception of the nature of the morphological method of research. It is of the order of events which led Owen to compare a cephalopod and a vertebrate, led Lacaze-Duthiers to regard the Tunicata and Lamellibranchs as allied; and with these and other heresies it must be denounced.

Passing to the third advance, extending over the last twenty years, it may be said to consist in the revival of a theory of 1829, which boldly asserts that Limulus is an Arachnid. In the development of the defense there have been two weak points but lately strengthened, viz, the insufficient consideration of the palæontological side of the question and of the presence of tracheæ among the Arachnida. Under the former there was, until recently, assumed the absence of the first pair of appendages in the Eurypterida; but it may be said that they have since been observed in *Eurypterus fischeri* of the Russia Silurian, and *E. scoticus* from the Pentland Hills, in both of which they consist of small chelate appendages flexed and limuloid in detail, somewhat reduced perhaps, and inclosed by the bases of the succeeding limbs, which become apposed as the anterior end is reached. Since by this discovery the Limuloids, Eurypterids, and Scorpionids are brought into a numerical harmony of limb-bearing parts, we may at once proceed to other points at issue. So far as the broader structural plan of Limulus and the Scorpion are concerned, all will agree to a general community, except for the organs of respiration; but concerning the cœlom, the mobile spermatozoa, and the more detailed features under which Limulous is held to differ from the Crustacea and to resemble the Arachnida, I would remark that while motile spermatozoa are characteristic of the Cirripedes, the rest of the argument is weakened, by the probability that the "arachnidan" characters which remain may well have been possessed by the crustacean ancestors, and that Limulus, though specialized, being still an ancient form, might have retained them. The difficulty does not seem to me to lie in this, nor with the excretory organs, if we are justified in accepting the aforementioned argument that the so-called Malpighian tubes may be inturned nephridia, ectodermal in origin, and in knowledge of the existence of endodermal excretory diverticula in the Amphipods. These facts would seem to suggest that as our experience widens, differences of this kind will disappear.

As to the tracheal system, now adequately recognized by the upholders of the arachnid theory, the presumed origin of tracheæ from lung books, the probability that the ram's-horn organ of the Chernetidæ may be tracheal, the presence of tracheæ in a simple form in the Acari, and, by way of an anomaly, in a highly organized form on the tibiæ of the walking legs of the harvest men (Phalangidæ), are all features to be borne in mind. While I am prepared to admit that this wide structural range and varied distribution of the tracheæ lessens their importance as a criterion of affinity, I can not accept as conclusive the evidence for the assumed homology between lung books and gills. And here it may be remarked that a series of paired abdominal vesicles, recently found in the remarkable arachnid *Kanenia*, invaginate as a rule, but in one example everted, seized upon in defense of this homology, have not been so regarded by those most competent to judge.

There remains the entosternite, an organ upon which much emphasis has been placed. Not only does a similar organ exist, apart from an endophragmal system, in *Apus*, *Cyclops*, some Ostracods and Decapods; but, regarding the question of its histology, it may be pointed out that from all that is at present known the structural differences between these several entosternites do not exceed those between the cartilages of the Sepia body. And when it is found that the figures and descriptions of the entosternite of *Mygale* ("Mygale sp.," "Mygalomorphous Spider," *auct.*) have been thrice presented upside down, the reliability of this portion of the argument is lessened, to say the least.

Recent observation has sought to clench the homology of the four posterior pairs of limbs of the King crab and Scorpion, by appeal to a furrow on the fourth segment in the former, believed to denote an original division into two; but I hesitate to accept this until myological proof has been sought.

Returning, amidst so much that is problematic, to the sure ground of paleontology, I wish to point out that when all is considered in favor of the arachnid theory there still remains another way of interpreting the facts.

In both Limulus and the Scorpion the first six of the eighteen segments are well known to be fused into a prosoma bearing the limbs, but while in the Scorpion the remaining twelve are free, in Limulus they are united into a compact opisthosomal mass. In dealing with the living arthropods, there is no character determinative of position in the scale of this or that series more trustworthy than the anteroposterior fusion of segments. It has been called the process of "cephalisation," and the degree of its backward extension furnishes the most reliable standard of highness or lowness in a given assem-

blage of forms. In passing from the lower to the higher Crustacea, we find this fusion increasing as we ascend; and it therefore becomes necessary to compare the Scorpion with the other Arachnida, Limulus with the Eurypterida, in order the better to determine the position of each in its respective series by the application of this rule.

As to the number of segments present, variation is a matter of small concern, in consideration of the mode of origin of segmentation and the wide numerical range—from seven in the Ostracods to more than sixty in Apus—the segments of the crustacean class present.

On the arachnidan side, in the Solifugæ but the third and fourth segments are fused; the remaining four of the prosomal series with the ten which remain are free. In *Kœnenia* four of the prosomal segments alone unite; the fifth and sixth with the rest are free. And when we pass to the Limuloids and the descending series of their allies, we find it distinctive of the Eurypterida that all the opisthosomal segments are free. If we can trust these comparisons, we must conclude that the Eurypterida of the past, in respect to their segmentation, simplify the Limuloid type, on lines similar to that on which the Solifugæ and Kœnenia simplify the Higher Arachnid and Scorpionid type, and that therefore if the degree of antero-posterior fusion of segments has the significance attached to it, *Limulus* and *Scorpio* must each stand at the summit of its respective series. If this be admitted, it has next to be asked if, in comparing them, we may not be comparing culminating types, which might well be isomorphic.

The scorpions are known fossil by two genera, *Palæophonus* and *Proscorpius*, from the Silurian of Gotland and Lanarkshire, the Pentland Hills, and New York State; while recent research, in the discovery of the genus *Strabops*, has traced the Eurypterida back to the Cambrian, leaving the scorpions far behind. One striking feature of the limbs of the Palæozoic Eurypterids is their constantly recurring shortness and uniformly segmented character, long known in *Slimonia*, and less conspicuously in *Pterygotus* itself, retained with development of spines in three of five known appendages of the recently described eurypterid giant *Stylonurus*. The minimum length yet observed for these appendages is that of the Silurian species *Eurypterus fischeri*, discovered by Holm in Russia in 1898. This creature is one of the few eurypterids in which all the appendages are preserved, and it is the more strange, therefore, that the advocates of the arachnid theory should ignore it in their most recent account. Allowing for the specialization of its sixth prosomal appendage for swimming, the fifth is but little elongated; the second, third, and fourth are each in total length less, by far, than the transverse diameter of the prosoma, and uniformly segmented, giving the appearance of

short antennæ. They seem to be seven jointed, and are just such appendages as exist in the simpler crustacean and tracheate forms; and in the fact that their structural simplicity is correlated with the independence of the whole series of opisthosomal segments they lend support to the argument for isomorphism.

With this conclusion we turn once more to the Scorpions, if perchance something akin to it may not be in them forthcoming. The Silurian genus *Palæophonus*, especially as represented by the Gotland specimen, reveals the one character desired. Its body does not appear to be in any marked degree simpler than that of the living forms; but on turning to its limbs we find the four posterior pairs, in length much shorter than those of any living species, all but uniformly segmented. In this they approximate toward the condition of the limbs of the Eurypterida just dismissed, and their condition is such that had they been found fossil in the isolated state they would have been described as the limbs of a Myriapod, and not of a scorpion at all. Indeed, their very details are what is required, since in the possession of a single terminal claw they differ from the limbs of the recent scorpions as do those of the Chilopoda from the hexapods.

With this the scorpionid type is carried back, with a structural simplification indicative of a parallelism with the other arthropod groups; and while the facts do not prove the total independence of the scorpionid and limuloid series they bring the latter into closer harmony with the Eurypterida of the past. They prove that the Silurian Scorpions simplify the existing Scorpionid type on precisely the lines on which the Eurypterida simplify the Limuloid: and they do so in a manner which suggests that a distinction between the *Crustacea vera* and the *Crustacea gigantostraca* (to include the Eurypterida and Xiphosura) is the nearest expression of the truth. It becomes thereby the more regrettable that in a recent revision of the taxonomy of the Limuloids the generic name *Carcinoscorpius* should have found a place.

I foresee the objection that the antenniform condition of the shorter limbs may be secondary and due to change. There is no proof of this. Against it, it may be said that the number of the segments is normal, and that where nature effects such a change elongation is with the multiarticulate state the only process known; as, for example, with the second leg of the Phrynidæ, the so-called second pareiopod of the Polycarpidea, and the last abdominal appendage of *Apseudes*.

That advances such as we have now considered should lead to new departures is a necessity of the case, and it but remains for me to remind you that within the last decade statistical and experimental methods have very properly come more prominently into vogue, in the desire to solve the problems of variation and heredity. Of the statis-

tical method, by no means new, I have but time to recall to you the presidential address of 1898 by my friend and predecessor in this chair, himself a pioneer; and of the experimental method I can but cite an example, and that a most satisfactory one, justifying our confidence and support. It concerns the late Professor Milne-Edwards, who in 1864 described, from the Paris Museum, the head of a rock lobster (*Palinurus penicillatus*) having on the left side an antenniform eyestalk. With the perspicuity distinctive of his race, he argued in favor of the "fundamental similarity of parts susceptible to revert to their opposite states." The matter remained at this till, on the removal of the ophthalmite of certain Crustacea, it was found that in regeneration it assumes a uniramous multiarticulate form, and it is an interesting circumstance that in the common crayfish the biramous condition normal to the antennule may occur—an example this of a fact which no other method could explain.

When all is said and done, however, it is to the morphological method that I would appeal as most reliable and sound. And when we find (1) that in certain Compound Tunicates the atrial wall, in the egg development delimited by a pair of ectoblastic invaginations, in the bud development may be formed from the parental endodermic branchial sac; (2) that regenerated organs are by no means derivative of the blastemata whence they originally arose; (3) that in the development of a familiar starfish the inner cells of the earliest segmentation stages, by intercalation among the outer, contribute half the fully formed blastula; (4) that there are Diptera in existence in which, while it is well nigh impossible to discriminate between the adult forms, there is reason to believe the pupa cases are markedly and constantly distinct, it becomes only too evident that the later embryonic and adult states are those most reliable for all purposes of comparison, and that it is by these that our animals can best be known and judged. Caution is, however, necessary with senility and age, since certain skulls have been found to assume at this period characters and proportions strikingly abnormal, and by virtue of the most important discovery, which we owe to the Japanese, that in certain Holothurians the calcareous skeletal deposits may so change with age as to render specific diagnoses based on their presumed immutability invalid. Advance, real and progressive, is in no department of zoological inquiry better marked than comparative morphology, and it is for the preeminence of this that I would plead. Educationally, it affords a mental discipline second to none.

We live by ideas, we advance by a knowledge of facts, content to discover the meaning of phenomena, since the nature of things will be forever beyond our grasp.

And now my task is done, except that I feel that we must not leave

this place without a word of sympathy and respect for the memory of one of its sons, an earnest devotee to our cause. William Thompson, born in Belfast, 1806, became in due time known as "the father of Irish natural history." By his writings on the Irish fauna, and his numerous additions to its lists, he secured for himself a lasting fame. In his desire to benefit others, he early associated himself with the work of the Natural History Society, which still flourishes in this city. He was president of this section in 1843, and died in London in 1852, while in the service of our association, in his forty-seventh year, beloved by all who knew him. His memory still survives; and if, as a result of this meeting, we can inspire in the members of the Natural History and Philosophic Society of this city, as it is now termed, and of its Naturalists' Field Club, an enthusiasm equal to his, we shall not have assembled in vain.

CORAL.[a]

By Dr. Louis Roule,

Professor at the University of Toulouse, France.

Will this beautiful material, whose color is so vivid and so pure, ever again come into fashion? It has fallen into complete discredit, easily supplanted by common glass jewelry and cheap pearls, yet there are signs of its return.

Recognized and appreciated in ancient times, it was known to be dredged from the depths of the sea, whence it appeared in the form of hard, arborescent masses like petrified branches, that even in this crude state showed color and bloom. It was also known that it was renewed by growth, for after several years it could again be gathered from a place that had previously been raked and worked. Its appearance and growth seemed to indicate that it was really a tree—a special sort of vegetable that grew at the bottom of the sea. It was classed with other living forms of diverse characters: Gorgonias, Antipathes, Madrepores, curious algæ encrusted with calcareous matter, and these singular productions of nature were termed "lithophytes," a name that accurately expressed the prevailing ideas concerning their nature. They were all much sought for, either as ornaments or as curiosities; but coral was by far the most valued. Its purplish tint, its hardness, the luster and polish which it readily took on, gave it the preeminence.

An Italian, Marsigli, who had been driven by political struggles into exile on the coasts of Provence, and his friend Peyssonel, a physician of Marseilles, were the first to recognize, a century and a half ago, the real nature of coral. Their observations, though accurate and sagacious, were so at variance with the beliefs of that period that Réaumur, to whom they were submitted, would not accept them, and thought it charitable to advise their authors to be more circumspect. According to them, coral was neither a stone nor a marine plant.

[a] Translated by author's permission from La Nature, Paris, No. 1509, April 26, 1902.

Their studies, especially those of Peyssonel, led them to consider it as an animal. Having taken coral recently gathered, they put it in a basin filled with sea water and examined it with care. The arborescent stone was covered with a softer flesh, likewise colored red, and on that flesh were living numerous animalculæ provided with movable tentacles. These creatures really formed a part of the flesh which ensheathes the stone, producing it as the organism of many animals produce the mineral substance of their shell or their skeleton. Peyssonel thus corrected one of the most serious errors of natural history. He not only placed in its true position an important group of marine creatures, but also corrected a mistaken view which had led to search in the wrong field for connecting links between the two great kingdoms of nature.

These investigations were so searching and thorough that an entire century passed before much was added to this discovery. It was about the middle of the last century that our knowledge of coral was increased by new acquisitions derived from the patient and persevering studies of an eminent French zoologist, H. de Lacaze-Duthiers, who has just left us after a life devoted wholly to science. From that time coral was understood.

The red stone is nothing less than the skeleton produced by minute animals, and serving for their support. Thanks to it they lift themselves above the rock to which this skeleton is attached, and maintain themselves erect in the water which surrounds them. This skeleton is arborescent, and its tree-like appearance gave rise to the ancient error concerning its nature. It has a trunk fixed on a solid support and knotted branches that extend in every direction. It is sometimes several feet in height and the thickness of its principal branches may be half an inch or more. Each trunk and branch carries, scattered over its surface, some millimeters apart, arranged without any apparent order, animals similar to each other, having the structure that characterizes the group of polyps. The bases of these creatures enlarge, thicken, and unite, forming by this union a sheet that surrounds the skeleton like a sheath, enveloping it wholly, following all its branches and nodosities. Together with the polyps, this is the living and fleshy portion, the "sarcosome" of the collection. Its internal surface is closely applied to the stony skeleton to which it gives origin; it produces it and continually secretes new layers in addition to those already existing. These layers are made of calcareous matter colored red by a special substance; the sarcosome secretes them as the mantle of a mollusk produces the shell that protects the animal.

The structure of each polyp is very simple. It is from 3 to 4 mm. in height and 2 to 3 mm. in diameter. Withdrawing at the slightest



A CORAL COLONY, SHOWING THE POLYPS OPENED.



FIG. 1.—FRAGMENT OF CORAL COLONY. POLYPS OPENED, SHOWING MOUTH AND TENTACLES.



FIG. 2.—A POLYP OF CORAL EXPELLING LARVÆ.

alarm and folding itself up with the greatest ease, so as to be almost indistinguishable from the sarcosome, it then shows on the surface only as a slight, barely visible, nipple-like projection. When expanded it bears at its summit eight delicate tentacles, with fringed borders, that can be moved about in every direction. The body itself, cylindrical in form, consists only of a delicate, transparent wall surrounding a spacious cavity, divided into compartments by eight vertical septa. This internal sac opens externally by a mouth in the middle of the space surrounded by the tentacles; at the other extremity it is prolonged as a canal that extends into the sarcosome, ramifies there, and unites with similar branches that originate from neighboring polyps. All intercommunicate by means of these canals. The entire assemblage is a colony, a polyp community in which each individual is joint-stock owner. Not only does their common skeleton sustain them all alike, the food seized by the tentacles of one does not nourish him alone, he shares it with his neighbors. They subsist upon small creatures which are digested and rendered assimilable in the interior cavity of the body. The polyps annually produce eggs upon the thin septa which divide this interior cavity. After fecundation is accomplished these eggs go on to develop without leaving the cavity, becoming free-swimming larvæ resembling microscopic worms whose surface is covered with vibratile cilia. These embryos swim about in the maternal cavity, finally pass out of the mouth, abandon their singular shelter, and wander forth at random. These beings are of such elementary structure that one organ performs all their functions.

Many of these larvæ are pursued, seized, and eaten by marine creatures stronger than they. Those which escape fix themselves, after a period of vagabond existence, to a rock or a shell and there become modified into polyps, growing external tentacles and internal septa. Then each polyp, far from remaining solitary, produces at its base expansions or buds which increase, develop, and in turn become polyps. This budding gives rise to a young colony, as yet minute and spread out over its support. The little sarcosome then commences to display its peculiar activity. It forms by secretion an outline of a calcareous skeleton, which it attaches to the support and constantly enlarges by the addition of new layers. On this it erects itself as on a protuberance. The colony continues to bud, the sarcosome to increase and to deposit new calcareous matter. The skeleton enlarges, elongates, and ensheaths itself with sarcosome, which constitutes for it an axis of support, this term being often used to designate it. It ramifies. The polyp community thus arises; it constantly increases, and it derives its origin from the minute larva engendered by one of the polyps of a neighboring community.

Coral is thus the product of an animal association. It is not the only one; other inferior creatures belonging to the class of polyps sustain and protect themselves by means of calcareous rods or envelopes produced in the same way. This is, however, one of the most characteristic and best known. Its history, save some variations of slight importance, applies to an entire group, and its principal interest depends upon the contrast between the weakness of the polyps and the great size of the polyp community. There, as everywhere, union is strength. The isolated individual counts for but little, but association and mutual aid produce great results. Man often might search in nature, even among the most minute beings, for rules for his conduct.

REINDEER IN ALASKA.[a]

By Gilbert H. Grosvenor,
Editor National Geographic Magazine.

Twelve years ago Dr. Sheldon Jackson brought his first herd of 16 reindeer across Bering Strait from Siberia and started his reindeer colony at Unalaska, off the bleak coast of Alaska. Many then smiled at the experiment and declared his plan for stocking the great barrens of northwestern Alaska with thousands of the animals which for centuries had been indispensable to the natives of Lapland and Siberia was impracticable and wasteful of time and good money. But the experiment prospered from the very first. Other reindeer, numbering nearly 1,000 in all, during the succeeding years were brought over from Siberia. To-day there are nearly 6,000 head in the various herds distributed along the Alaskan coast from Point Barrow to Bethel. The existence of the 30,000 natives of northwestern Alaska, as well as the success of the miners who are beginning to throng into the interior of the Territory in the far north, are dependent upon these domestic reindeer; their clothing, their food, their transportation, their utensils, and their shelter are all furnished them by the reindeer.

The reindeer enterprise is no longer an experiment, although still in its infancy. There are 400,000 square miles of barren tundra in Alaska where no horse, cow, sheep, or goat can find pasture; but everywhere on this vast expanse of frozen land the reindeer can find the long, fibrous, white moss which is his food. There is plenty of room for 10,000,000 of these hardy animals. The time is coming when Alaska will have great reindeer ranches like the great cattle ranches of the Southwest, and they will be no less profitable.

The story of the inception and growth of the reindeer enterprise in Alaska is very interesting and is not generally known. During an

[a] Reprinted by permission from the National Geographic Magazine, Vol. XIV, No. 4, April, 1903.

extended trip of inspection of the missionary stations and Government schools in Alaska in the summer of 1890,[a] Dr. Sheldon Jackson was impressed with the fact that the natives in arctic and subarctic Alaska were rapidly losing the sources of their food supply. Each year the whales were going farther and farther north, beyond the reach of the natives, who had no steamships in which to pursue them; the walrus, which formerly had been seen in herds of thousands, were disappearing; the seals were becoming exterminated, and in winter the Eskimo had to tramp 15 to 20 miles out on the ice before he could catch one. The modern hunter, with his steam launches and rapid-fire guns, had found the whales, walrus, and seals such easy prey that he was ruthlessly destroying them. Also the wild caribou, that the native had easily captured before, had been frightened away and was rarely seen.

Not only was the Eskimo losing his food, but what in an arctic climate is no less important, his clothing as well. The whalebone, the ivory tusks of the walrus, the seal skin, and the oil had given him means of barter with the Siberian traders across the strait, from whom he obtained reindeer skins to keep him warm in winter.

Dr. Jackson saw that unless something was done at once the United States would have to choose between feeding the 20,000 and more natives or letting them starve to death. The latter course was impossible, the former rather expensive, as supplies would have to be carried some 3,000 miles from Seattle. The more enterprising Siberian, living on the opposite side of the strait under practically the same conditions of arctic cold, got along very nicely, as he had great herds of domestic reindeer to fall back upon when game was scarce. The same moss which covered so many thousands of miles of the plains of arctic Siberia was seen everywhere in Alaska. The tame reindeer of Siberia was practically the same animal as the wild caribou of Alaska, changed by being domesticated for centuries. Could not the Eskimo be made self-supporting by giving him reindeer herds of his own?

On his return to the United States in the winter of 1891 Dr. Sheldon Jackson, in his annual report to Congress, asked for an appropriation to provide the money for importing a few deer. Congress was not convinced of the wisdom of such action, but several private persons were so interested that they placed $2,000 at Dr. Jackson's disposal to begin the experiment. The first deer were brought over that year. It was not long, however, before the Government realized the importance of the movement, and in 1894 appropriated the sum of

[a] Dr. Sheldon Jackson first visited Alaska in 1877, in the interest of schools and missions. He made a second trip in 1879. Other visits followed, and since his appointment as general agent of education in Alaska in 1885 he has made annual visits to the Territory.



HERD OF REINDEER CROSSING A RIVER IN SIBERIA.

From a photograph by Chief Engineer H. W. Spear, R. C. S.



PROSPECTING FOR GOLD IN ALASKA.

$6,000 to continue the work. Later the appropriation was increased, and during the last several years has amounted to $25,000 annually.[a]

The Siberians were at first unwilling to part with any of their reindeer. They were superstitious and, above all, afraid of competition and loss of trade across the strait. In 1891 Capt. M. A. Healy, Revenue-Cutter Service, commanding the U. S. S. *Thetis*, was instructed to convey Dr. Sheldon Jackson to Siberia and furnish him every possible facility for the purchase and transportation of reindeer from Siberia to Alaska.

In carrying out these instructions Captain Healy was obliged to sail from village to village for 1,500 miles along the Siberian coast before he found an owner willing to barter his reindeer for American goods. None would sell the deer for cash. Of recent years the Siberians have been but little less reluctant to part with their deer, though they could easily spare many thousands from their vast herds without knowing it.

The first deer brought over were from the Chukches herds—a tough and hardy breed. Two years ago Lieutenant Bertholf, Revenue-Cutter Service, was commissioned to go to Siberia and to purchase some of the Tunguse stock, which are larger, stronger, and sturdier. Starting from St. Petersburg, after a long journey across Siberia, much of it by sled, he succeeded in purchasing several hundred Tunguse reindeer near Ola, hired a steamer, embarked the reindeer at Ola with 2,500 bags of reindeer moss, and finally landed 200 of the animals in good condition at Port Clarence. His experiences during his remarkable journey were most interesting, and are admirably described in his report to Dr. Sheldon Jackson, published in 1902.[b]

[a] Congressional appropriations for the introduction into Alaska of domestic reindeer from Siberia are as follows:

1894	$6,000	1900	$25,000
1895	7,500	1901	25,000
1896	7,500	1902	25,000
1897	12,000	1903	25,000
1898	12,500		
1899	12,500	Total	158,000

Congress intrusts the general charge of the work to the Bureau of Education, of which Dr. William T. Harris is the distinguished head; the formulation of plans and their execution is intrusted to Dr. Sheldon Jackson, general agent of education in Alaska. Dr. Harris, in his annual reports to Congress, has vigorously urged the importance of the work, and to him credit is due for a large share of its success. Capt. M. A. Healy, and the many officers of the Revenue-Cutter Service, whose vessels have, year after year, carried the agents of the Bureau back and forth and brought the reindeer from Siberia without charge, have also contributed to the success of the reindeer enterprise.

[b] "Report on the Introduction of Domestic Reindeer into Alaska," by Sheldon Jackson, LL. D., 1901. Appendix, Expedition to Siberia, report of Lieut. E. P. Bertholf, Revenue-Cutter Service, pp. 130–168.

THE ESKIMO AS HERDERS.

With careful training the Eskimo make excellent herders. They are by nature good imitators, though not inventive, and readily learn how to take care of the reindeer, to throw the lasso, to harness and drive the deer, and to watch the fawns. Siberian herders were at first imported to teach them, and later the more intelligent and efficient Laplanders, who have learned by centuries of experience to give to the breeding of reindeer the care that we give to the breeding of cattle. In the winter of 1898 sixty-three Laplanders and their families volunteered to go to Alaska, the United States Government paying the expenses of their long journey of 10,000 miles. When their term of enlistment expired some reenlisted, some of them went home again, but the majority turned miners. Everyone will be glad to know that at least two-thirds of the whole number made fortunes in the Cape Nome gold fields.

The reindeer herders have to be watchful. Now and then reckless miners try to plunder the herds, or by their carelessness set fire to the moss. A fire will sweep over the moss barrens, licking up every fiber of the moss, as it sweeps over our western prairies. A moss fire is even more destructive, for many years pass before the moss will grow again.

At the end of a year's service the Government makes a gift to deserving herders of two or more reindeer.

REINDEER RAISING AS AN INDUSTRY.

When one considers that raising reindeer in Alaska is simple and the profits enormous, one is surprised that as yet no one has really gone into the reindeer business, especially at Nome, where a rich market awaits the reindeer farmer.

A fawn during the first four years costs the owner less than $1 a year. At the end of the four years it will bring at the mines from $50 to $100 for its meat, or if trained to the sled or for the pack, is easily worth $100 to $150.

The fawns are very healthy and but few die. The does are prolific, and after they are 2 years of age add a fawn to the herd each year for ten years. Last year, out of 50 does 2 years and more of age in one herd, 48 had fawns, and of these only five died, three of which were lost through accidents or by the carelessness of the herder.

The reindeer are so gregarious and timid that one herder can easily guard 1,000 head. The herder knows that if a few stray off he need not look for them, as they will soon become frightened and rejoin the main herd.

The does make almost as good sled deer as the bulls and geldings, though they are slightly smaller and less enduring.



REINDEER HERD, SIBERIA.

U. S. Revenue Cutter *Bear* in the offing. From a photograph by A. Weeks, M. D.



FIG. 1.—OUTLINE MAP SHOWING GOVERNMENT REINDEER STATIONS IN ALASKA.



FIG. 2.—REINDEER ON THE SIBERIAN BEACH, HOBBLED, WAITING TO BE LOADED ON THE BEAR FOR TRANSPORTATION TO ALASKA.

From a photograph by R. N. Hawley, M. D.

The Chukches deer cost in Siberia about $4 a head for a full-grown doe or bull. The fawns born in Alaska are larger and heavier than the parent stock. The Tunguse deer cost nearly $7.50 apiece. By the addition of the Tunguse breed it is hoped that the Alaska stock will be improved and toughened.

The reindeer cow gives about one teacupful of very rich milk, nearly as thick as the best cream, and making delicious cheese. Mixed with a little water, the milk forms a refreshing drink. The Siberians and Laplanders save the blood of slaughtered deer and serve it in powdered form. From the sinews tough thread is obtained.

REINDEER EXPRESS.

The Alaskan reindeer can hardly equal the speed of the Lapland deer, which Paul Du Chaillu[a] describes as making from 150 to 200 miles a day, and sometimes 20 to 25 miles down hill in a single hour. A pair of them can pull a load of 500 to 700 pounds at the rate of 35 miles a day and keep it up weeks at a time. W. A. Kjellmann drove his reindeer express one winter 95 miles in a single day.

In the winter of 1899 and 1900, between St. Michael and Kotzebue, under the Arctic Circle, and between Eaton and Nome, Alaska, and in the winter of 1901 and 1902, between Nome and Candle, on the Arctic Ocean, the United States mails were carried with reindeer teams.[b] Upon the latter route the teams had heavy loads of passengers and freight and made the distance in eight days. Dog teams would have required fifteen to twenty days for the trip.

The reindeer can travel at night as well as in the daylight, and thus during the long arctic night, when dogs are inefficient, transportation is always possible with a reindeer team.

The reindeer make good packers in summer. One hundred and fifty pounds is a fair load. They also can be ridden in the saddle, but not with much comfort until the rider learns how to adjust himself. In the Tunguse country the natives use their deer in summer as we would a mule or horse. It is no uncommon sight to see a Tunguse trotting along the shore deerback.

Lieutenant Bertholf describes the caravans of reindeer sleds in northeastern Siberia. Over 1,000 sleds leave Ola during the winter in caravans of about 100 each. A caravan of 100 sleds is managed by 10 men. Some years ago the Russian Government used horses on the caravan route from Ola to the Kolima River, but recently substituted reindeer, and now saves $60,000 yearly by the change.

[a] "The Land of the Long Night," Paul Du Chaillu. Charles Scribner's Sons.

[b] Since the above was written the United States Government has given a contract to Mr. S. R. Spriggs, of Point Barrow, Alaska, to carry the winter mail between Kotzebue and Barrow with reindeer teams. This is the most northern mail route by land in the world.

The illustration, Figure 2, Pl. VI, shows the leaders of Lieutenant Bertholf's party breaking a path through snow that reached to the belly of the deer. A strong wiry deer, unmounted, was driven first. In the deep snow he could advance only by jumps, but his leaps broke the way somewhat for the next few deer, who were also unmounted. After a dozen or more unmounted deer had passed by, deer ridden by a boy and girl broke the path still further until deer with heavy loads could pass. Lieutenant Bertholf in this way broke his path for 160 miles through the deep snow.

When the caravan halts the deer are turned out to pasture untethered and allowed to wander as they will. The driver uses a switch to touch up the slothful, but "some of the old deer do not seem to mind a switch any more than does an army mule."

The illustration, Plate XI, shows a number of reindeer digging up the snow with their powerful hoofs to get at the moss beneath the snow. As soon as spring comes the deer abandons his diet of moss, which seems to be most nutritive in winter, for willow sprouts, green grass, and mushrooms. The hoof of the reindeer is as wide as that of a good-sized steer and prevents him from settling down into damp snow or miry soil.

REINDEER LOANED BY THE GOVERNMENT.

The United States Government loans a certain number of the reindeer to the mission stations, or to individuals who have shown their ability, reserving the right, after three or five years, of calling upon the mission station or the individual for the same number of deer as composed the original herd loaned. In 1894 the Congregational mission at Cape Prince of Wales was granted the loan of 100 deer. The mission has since paid back the loan, and now possesses in its own right 1,000 head.

A few of the herds, notably that at Cape Prince of Wales, have grown so large that the owners are able to kill off some of the extra males for food for the families of the herders and to sell others to the butchers in the neighboring mining camps. Last year deer for slaughter brought at some of the mining camps from $60 to $100 each, while for male deer trained to harness miners gave as much as $150 apiece. The herders at this same station earned last winter $600 in gold for freighting with their reindeer to the mining camps. The deer were worked in double trace harness like horses, and hauled on sleds 790 pounds each.

Of the 60 individual owners of domestic reindeer in Alaska to-day 44 are Eskimo. Most of them have served a five-year apprenticeship, and having earned their deer are competent to care for them.

Each owner has his own individual mark, which is branded on the left or right ear of each of his deer.



MR. T. L. BREVIG STARTING ON A FAMILY SLEIGH RIDE, TELLER REINDEER STATION.

From a photograph by Kleinschmidt.



TRAVELING WITH REINDEER IN SUMMER.



BREAKING A PATH THROUGH DEEP SNOW.

From a photograph by E. P. Bertholf.



FREIGHTING WITH REINDEER, CAPE PRINCE OF WALES.



MILKING REINDEER, TELLER REINDEER STATION.

From a photograph by Tappan Adney.

IMPORTANCE OF REINDEER TO MISSION STATIONS.

The Bureau of Education hopes that in time each mission station will possess a herd of at least 5,000 head. A reindeer herd at a mission station in arctic or subarctic Alaska means, says Dr. Jackson:

"First. The permanence of the mission. Without it the natives are away from home a larger portion of the year in search of food, and, since the advent of the miners, are inclined to leave their homes and congregate in the American villages at the mines, where they live by begging and immorality and soon disappear from the face of the earth.

"Second. It affords the missionary the opportunity of rewarding and encouraging those families that give evidence of being teachable by establishing them in the reindeer industry, and thus greatly promoting their material interests.

"Third. With the increase of the herd it becomes a source of revenue through the sale of the surplus males at remunerative prices to the miners and butchers. In a few years this revenue should be sufficient to entirely support the mission and thereby relieve the treasury of the central missionary society.

"Fourth. The possession of a herd insures to the mission family a continuous supply of fresh meat. This, to a family which is compelled to live largely upon salted and canned meats and canned vegetables, is of no small benefit, promoting their comfort, health, and usefulness.

"Fifth. Reindeer trained to harness and sleds greatly increase the efficiency and the comfort of the missionary in ministering to outlying native settlements."

REINDEER FROM LAPLAND.

The vast majority of the American people have an idea that the reindeer experiment in Alaska proved a failure long ago, simply because of the widely advertised attempt in 1898.

In December, 1897, rumors were started that American miners in the Yukon Valley were in danger of starvation. Congress appropriated a large sum for their relief, and commissioned Dr. Sheldon Jackson to go to Norway and Sweden to purchase 500 reindeer broken to the harness, with sleds, harness, and drivers, for hauling supplies from the head of Lynn Canal to the destitute miners, 1,000 miles away.

Dr. Jackson reached Bosekop, Lapland, in January, purchased 526 trained deer, gathered 68 Lapp drivers with their families, embarked them all on one ship, and sailed for New York from Trondhjem February 4. Only one deer died on the voyage of twenty-four days, though the trip was a most tempestuous one, and the deer in pens on the deck were drenched day and night by the seas that broke over them. At New York special trains met the expedition and carried them across the continent to Seattle without the loss of a single deer. Then the troubles began. The supply of moss brought from Norway became exhausted, and the deer did not like the grass of Seattle. There

was delay in securing a vessel to transport the expedition to the head of Lynn Canal, and further delays at Lynn Canal and no moss to be found there.

Nearly 300 of the reindeer died of starvation after reaching the coast of Alaska, because of the failure of the Government to have ready suitable arrangements for pushing the herd from the seashore to the moss fields at the head of Chilkat River, 50 miles distant. The remaining 200, weakened by starvation, were driven to the Yukon Valley by easy stages, and the relief expedition was abandoned, but, fortunately, not before the country had learned that the miners in the Yukon had abundant supplies and that the relief expedition had been unnecessary. The Laplanders who had been brought over were distributed among the reindeer stations and employed to teach the natives.

This expedition to Lapland was in no way connected with the general plan of introducing domestic reindeer into Alaska. The reindeer procured by it were all geldings trained to harness. The reindeer for breeding purposes have all been brought from Siberia.

RELIEF OF WHALERS AT POINT BARROW.

The first forcible realization of the wisdom of the Government in stationing reindeer herds in Alaska came to the American people in the winter of 1897–98. In the fall of 1897 word was received that eight whaling ships had been imprisoned in the ice near Point Barrow, and that the 400 American seamen aboard were stranded without food for the long winter till the ice should open in July. No vessel of relief could get within 2,000 miles of the party, or nearer than Denver is to Boston. There was no known method by which provisions could be dragged overland. If the Government had not five years before commenced the introduction of the reindeer, most of these 400 men would have starved to death before help reached them. Fortunately, there were large herds of reindeer at Cape Nome and at Cape Rodney, over 1,000 miles by land from Point Barrow, or farther than Chicago is from New York. The Government hurried the revenue-cutter *Bear*[a] north from Seattle, carrying three brave volunteers—Lieut. David H. Jarvis, Lieut. Ellsworth P. Bertholf, and Dr. Samuel J. Call. The three men were landed December 16, 1897, at Cape Vancouver, obtained some dog teams from the natives, and commenced their dreary journey of 2,000 miles through the arctic night to Point Barrow. They collected about 450 reindeer from the herds at Rodney and Nome, and then, with reindeer instead of dog sleds, and with Mr. W. T. Lopp, agent of the American Missionary Society at Cape Prince of Wales, and Charley

[a] For twenty years the revenue-cutter *Bear* has been engaged in Arctic work. It has saved the lives of hundreds of wrecked whalers, and contributed more to the comfort and safety of the settlements along the Alaskan coast than any vessel in the service.



FIG. 1.—TRAVELING DEERBACK THROUGH DEEP SNOW.

From a photograph by E. P. Bertholf.



FIG. 2.—LIEUTENANT BERTHOLF MOUNTED ON REINDEER, SHOWING THE ABILITY OF THE REINDEER TO CARRY 210 POUNDS.



REINDEER TETHERED DURING A HALT.

Arisartook, a native, and several herders, they pushed on through the storms and bitter cold of an arctic winter, driving the deer before them. After a journey of three months and twelve days, on March 29, 1898, they reached the destitute whalers, just in time to save them from great suffering and death.

In heroism, pluck, and endurance the journey of these men has rarely been equaled. Congress voted its thanks to the gallant rescuers and awarded them special medals of honor, but in the excitement aroused throughout the country by the rapid succession of events of the Spanish-American war their work was almost unnoticed.

Since that time a reindeer herd has been kept at Point Barrow, so there is no longer danger of ice-imprisoned whalers perishing from starvation. The experience also showed the faithfulness of the Eskimo. Mr. Lopp had left his wife at the station, the only white person among 400 natives, but during his absence of nearly five months she received nothing but constant courtesy and kindness from them.

DEVELOPMENT OF ARCTIC AND SUBARCTIC ALASKA DEPENDENT ON THE REINDEER.

The original motive in bringing the reindeer to Alaska was purely philanthropic—to give the native a permanent food supply.

Since then the discovery of large and valuable gold deposits upon the streams of arctic and subarctic Alaska has made the reindeer a necessity for the white man as well as for the Eskimo. Previous to the discovery of gold there was nothing to attract the white settler to that desolate region, but with the knowledge of valuable gold deposits thousands will there make their homes, and towns and villages are already springing into existence.

But that vast region north of the arctic circle, with its perpetual frozen subsoil, is without agricultural resources. Groceries, breadstuffs, etc., must be procured from the outside. Steamers upon the Yukon can bring food to the mouths of the gold-bearing streams, but the mines are often many miles up these unnavigable streams. Already great difficulty is experienced in securing sufficient food by dog-train transportation and the packing of the natives. The development of the mines and the growth of settlements upon streams hundreds of miles apart necessitate some method of speedy travel. A dog team on a long journey will make on an average from 15 to 20 miles a day, and in some sections can not make the trip at all, because they can not carry with them a sufficient supply of food for the dogs, and can procure none in the country through which they travel. To facilitate and render possible frequent and speedy communication between these isolated settlements and growing centers of American civilization, where the ordinary roads of the States have no existence and can not

be maintained, except at an enormous expense, reindeer teams that require no beaten roads, and that at the close of a day's work can be turned loose to forage for themselves, are essential. The introduction of reindeer into Alaska makes possible the development of the mines and support of a million miners.

The reindeer is to the far north what the camel is to desert regions, the animal which God has provided and adapted for the peculiar, special conditions which exist. The greater the degree of cold, the better the reindeer thrives. Last winter a party with a reindeer team made a day's journey with the temperature at 73° below zero. On a long journey through an uninhabited country a dog team can not haul sufficient provisions to feed themselves. A deer with 200 pounds on the sled can travel up and down the mountains and over the plains without a road or trail from one end of Alaska to the other, living on the moss found in the country where he travels. In the four months' travel of 2,000 miles, from Port Clarence to the Kuskokwim Valley and back, by Mr. W. A. Kjellmann and two Lapps, with nine sleds, 1896–97, the deer were turned out at night to find their own provisions, except upon a stretch of the Yukon Valley below Anvik, a distance of 40 miles.

The great mining interests of central Alaska can not realize their fullest development until the domestic reindeer are introduced in sufficient numbers to do the work of supplying the miners with provisions and freight and giving the miner speedy communication with the outside world.

The reindeer is equally important to the prospector. Prospecting at a distance from the base of supplies is now impossible. The prospector can go only as far as the 100 pounds of provisions, blankets, and tools will last, and then he must return. With ten head of reindeer, which he can manage single handed, packing 100 pounds each, making half a ton of supplies, he can go for months, penetrating regions hundreds of miles distant.

FUTURE OF REINDEER INDUSTRY.

Even if no more reindeer are imported from Siberia, if the present rate of increase continues, doubling every three years—and there is no reason why it should not—within less than twenty-five years there will be at least 1,000,000 domestic reindeer in Alaska. This is a conservative estimate and allows for the deer that die from natural causes and for the many that will be slaughtered for food. In thirty-five years the number may reach nearly 10,000,000 head and Alaska will be shipping each year to the United States anywhere from 500,000 to 1,000,000 reindeer carcasses and thousands of tons of delicious hams and tongues. At no distant day, it may be safely predicted, long reindeer trains from arctic and subarctic Alaska



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REINDEER DIGGING UP THE SNOW TO GET THE MOSS BENEATH.

Republished from "Land of the Long Night," by Paul du Chaillu, by courtesy of the publishers.

will roll into Seattle and our most western cities like the great cattle trains that now every hour thunder into the yards of Chicago. Before the end of the present century Alaska will be helping to feed the 200,000,000 men and women who will then be living within the present borders of the United States.

REFERENCES.—For further information on the introduction of domestic reindeer into Alaska, consult the annual reports of Sheldon Jackson, LL. D., general agent of education in Alaska, for 1891–1902. The reports contain much interesting matter about Alaska as well. They may be obtained from the superintendent of public documents, Washington, D. C., for a small sum.

Special mention may be made of the following articles included in the reports:

"Domesticated Reindeer, with Notes on the Habits and Customs of the Eskimo and Life in Arctic Alaska," including many quaint native drawings, by Miner W. Bruce, pp. 25–117, 1893.

"The Itinerary of 1895" (describes a tour of inspection), by Dr. William Hamilton, assistant general agent of education in Alaska, pp. 21–41, 1895.

"Report of Wm. A. Kjellmann Describing a Trial Trip of 2,000 Miles with Nine Reindeer Sleds," pp. 41–71, 1897.

"The Lapland Reindeer Expedition of 1898," pp. 32–46, 1898.

"Expedition to Siberia," by Lieut. E. P. Bertholf, describing the purchase of Tunguse reindeer in Siberia, pp. 130–168, 1901.

"Reindeer in Siberia," pp. 168–175, 1901.

Mention should also be made of:

"The Cruise of the U. S. Revenue Cutter *Bear* and the Overland Expedition for the Relief of the Whalers in the Arctic Ocean, November 27, 1897, to September 13, 1898," including reports of Lieut. D. H. Jarvis, Lieut. E. P. Bertholf, and Surg. S. J. Call. Government Printing Office, 1899.

"Commercial Alaska in 1901," by Hon. O. P. Austin, Bureau of Statistics, Treasury Department, pp. 3985–3989.

A MARINE UNIVERSITY.

By W. K. Gregory,

Assistant to Prof. H. F. Osborn, of the American Museum of Natural History, New York.

[While the plan of this article, and especially the introductory and concluding paragraphs, is original, the rest is largely adapted and extracted from an article in Harper's Monthly Magazine for March, 1902, by Professor Osborn, for some time president of the trustees of the Marine Biological Laboratory, supplemented by extracts from the ninth report of the Marine Biological Laboratory for the years 1896–1899, and from Prof. E. G. Conklin's article in Science, March 2, 1900.]

The prevailing spirit at Woods Hole is the spirit of exploration. The pure delight of discovery sustained Darwin in his classic voyage on the *Beagle* and Huxley in his cruise on the *Rattlesnake*. These great names indorse the statement that even in themselves, from the simple natural history standpoint, the phenomena of marine life are worthy of intimate and ardent study. But Darwin is forever famous not chiefly for his life-long natural history observations, but for the grand theory gleaned therefrom—the theory of evolution by means of natural selection; and the most enduring monuments to Huxley are not only his brilliant contributions to systematic zoology, but especially his clear statement of all life phenomena as essentially protoplasm phenomena. Accordingly the spirit of exploration at Woods Hole manifests itself in the simultaneous pursuit of (*a*) natural history and evolution, and (*b*) biology, the study of the nature of life itself as found in protoplasm.

The enthusiasm for natural history at the Marine Biological Laboratory is in part an inheritance from Louis Agassiz, who may be considered in a sense as its founder. With Carl Vogt, of Geneva, Huxley, Dohrn, and other great naturalists, Agassiz realized the important results which would flow from the study of marine life in the living and fresh condition afforded only by a close proximity to the seashore. This idea happily culminated in 1870, when Prof. Anton Dohrn founded the beautiful and resourceful station of Naples—the great Mecca of all students of marine life.

Agassiz brought with him, therefore, to America, along with his other enthusiasms that for marine stations. In 1873 an eloquent

address of his caught the eye of a New York merchant, Mr. John Anderson. Our first seaside laboratory was established on the little island of Penikese, off the coast of Massachusetts, and for one memorable season a group of men who have since exerted a profound influence upon natural history worked under this inspiring master. All have become leaders, but notably A. Agassiz, Brooks, Jordan, Lyman, Mayer, Morse, Putnam, Whitman, and Wilder. "Study nature, not books" and other mottoes embodying Agassiz's Socratic theory of teaching zoology adorned the walls of this plain pine building, and have fortunately been preserved to perpetuate their influence at Woods Hole. After a second season, following the death of Agassiz in December, 1873, this laboratory, somewhat too isolated, as it proved, was abandoned. All the credit for reviving the work belongs to Boston, especially to a number of ladies, who, in financial cooperation with Professor Hyatt and the Boston Society of Natural History, founded a new laboratory at Annisquam, which in 1888 was finally transplanted to Woods Hole. With Prof. C. O. Whitman, one of the distinguished pupils of Agassiz, as its director, and with the Penikese mottoes upon its walls, we may thus consider Woods Hole as the offspring of the Anderson school. Prof. Charles L. Minot, of Harvard, and Mr. Edward G. Gardiner, of Boston, have been active in its support. But the administration has gradually become thoroughly national in character, including representatives of all the larger Eastern and Western universities.

Almost midway between the island of Marthas Vineyard and the mainland, and separating Buzzards Bay from Vineyard Sound, is the long chain of the Elizabeth Islands, which are strung out from the southwestern extremity of Cape Cod. Woods Hole is situated at the apex of this extremity and just at the beginning of the chain. Of all points along the coast this is the best adapted physically for a seashore laboratory. About ten years after the abandonment of Penikese, Spencer F. Baird selected this spot after having investigated almost every available point on the Atlantic coast Here he succeeded in establishing the splendid station of the United States Fish Commission, with its fleet of vessels and extensive laboratory facilities, designed for the investigation and artificial culture of all edible forms of sea life, and a sympathetic and active factor in the prosecution of pure scientific research. This national station under the administration of Goode, Bumpus, and others has been a resourceful and willing ally of the biological laboratory.

The natural advantages of Woods Hole deserve especial emphasis. The waters of Buzzards Bay and Vineyard Sound are of exceptional purity. In the immediate vicinity of Woods Hole are numerous harbors and lagoons, with muddy, sandy, or rocky bottoms, while the coast is so broken by bays, promontories, straits, and islands as to afford the most varied environments for marine life. In addition the



Erected, 1892. 1894. 1896.

FIG. 1.—MARINE BIOLOGICAL LABORATORY, WOODS HOLE, MASS., JANUARY 28, 1896.



FIG. 2.—LABORATORY, U. S. FISH COMMISSION.



SAGITTA AND VIGILANT.

tide currents which sweep in through the "hole" bring in multitudes of floating animals and plants, many of which are tropical forms, carried in from the Gulf Stream, which is distant only about 100 miles. The proximity of the Gulf Stream to this portion of the New England coast gives a laboratory located at this point many of the advantages of a tropical station without any of the accompanying disadvantages. There are also many fresh-water ponds and lakes in the vicinity which contain a rich fauna and flora.

In these ideal collecting grounds the trained investigator naturally finds abundant and widely varying material, and the beginner in zoology, during the frequent excursions which form so prominent a feature of the instruction, sees something under natural conditions of the teeming life of the shore and of shallow water, of the delicate fauna found on spiles and floating timbers, and of the products of the dredge and drag net. It is under such circumstances that one enthusiastically realizes the meanings of various structures made out in the dissecting pan in the laboratory, and the nicety of the adaptations of each animal to the conditions under which it lives. Much of the collecting is carried on in the steam launch *Sagitta*, suggestively named after a swift-swimming marine worm of arrow-like shape.

The naturalist and the student are also fortunate in the material and educational equipments of the laboratory. It is true that in contrast with the beautiful Renaissance building at Naples our gray-shingled laboratory buildings seem somewhat barn-like externally. However, this is not incompatible with the true scientific spirit of "plain living and high thinking." Certainly the very best equipment and facilities that ingenuity, stimulated by necessity, can provide is most generously devoted to the advancement of science. Fifty private rooms, for example, are reserved each year for independent investigators, and these are free of expense.

Under the heading "equipment" one should briefly touch upon the department of supply, the museum, and the library, and especially upon some of the various courses of instruction.

The department of supply was established in order to make accessible to teachers and others at a distance, who desire to obtain material for study or class work, the products of the teeming collecting grounds at Woods Hole. All the types generally used in both zoological and botanical instruction, such as algæ, sponges, hydroids, starfishes, sea urchins, marine worms, crustaceans, mollusks, smaller marine vertebrates, etc., as well as mounted sets of seaweeds, are kept in stock. A special laboratory for this department, supplied with salt and fresh water for aquaria, has been prepared, and a curator appointed to keep the department open throughout the year. The department is also securing materials for the museum, illustrating the fauna and flora of the surrounding waters and country. There is a rapidly growing collection of dissections largely prepared by the classes in zoology,

another collection of microscopical preparations, and finally an herbarium. All who have taught or studied biology do not need to be told the immense educational value of these collections. The library—in any institution, the fount to which all constantly repair—is provided with many works of reference and the more important journals on zoology and botany; but the expansion of science is so rapid that a library of this kind is always urgently in need of frequently called-for titles.

All these elaborate adjustments for studying the morphology and evolution of marine organisms furnish the data for another set of studies, above alluded to under the term "biology."

In his famous address "On the physical basis of life," Huxley said:

> Thus a nucleated mass of protoplasm turns out to be what may be termed the structural unit of the human body. * * * Beast and fowl, reptile and fish, mollusk, worm, and polype are all composed of structural units of the same character, namely, masses of protoplasm with a nucleus. * * * Hence it appears to be a matter of no great moment what animal or plant I lay under contribution for protoplasm, and the fact speaks volumes for the general identity of that substance in all living beings.

The unity of protoplasm is the ultimate raison d'être for the Woods Hole laboratory. In the protoplasm of a polype may be wrapped up a secret of vast importance to the welfare of the human race.

This is the thought underlying the courses in comparative physiology and embryology, as shown in the following quotations:[a]

> * * * It is our problem to get an understanding of the various life phenomena. It happens that while the solution of one physiological problem is almost impossible among certain vertebrates or certain arthropods, the conditions in one definite arthropod or in an ascidian, or some other animal may be such as to make the solution almost self-evident. In the various forms of the animal kingdom nature has prepared just as many experiments as we might wish to accomplish by our vivisectional method, but without the disadvantages of that method. We can, for example, study the automaticity of contractile tissue far more readily in the pulsatile bell of the medusa than in the vertebrate heart. In the medusa, by one snip of the scissors, we have a contractile tissue deprived of nerves without elaborate vivisection. The influence on protoplasm of lack of oxygen may also be readily studied from a comparative standpoint. From the chemical transformations going on in large masses of similar cells the inference may be drawn that cells deprived of oxygen undergo hydrolytic splittings by which insoluble bodies may become soluble. But by placing various infusoria or developing eggs under the microscope this fact may with ease be rendered visible. The membranes and more solid portions of the infusorian may be seen to dissolve and disappear, leading to a complete disorganization of the cell. * * * It may truthfully be said that the problem of heredity is one of the most important problems of physiology at the present time. The reasons why a given mass of cells develops into a given organ of a certain shape, size, and position can evidently only be ascertained by experimental physiology. The study of the phenomena of development and organization must hence form a part of any course in comparative physiology.

[a] Ninth report of the Marine Biological Laboratory, 1896, 199.

Accordingly, we learn, about two weeks of the course are devoted to this study. The experiments deal with the influence of various factors in the environment (light, heat, gravity, chemicals, etc.) and in the organism which determine the development of given organs and the attainment of the proper animal form; with regeneration of animals; with the influence on protoplasm of various external factors, such as lack of oxygen, temperature, ion effects, and so on. This is followed by an experimental course illustrating tropisms,[a] geotropism, heliotropism, stereotropism, chemotropism, galvanotropism. Among the forms studied will be copepods, worms, limulus larvæ, arenicola larvæ, fundulus and arbacia eggs, the shrimp, etc.

A fourth week of the course is given to "the study of the comparative physiology of the central nervous system. Phenomena of automaticity, coordination, and of reflexes, the transmission of nerve impulses independent of nerves, and reactions to injury, will be illustrated in many forms of life. Unusual facilities are offered for work of this character owing to the immense number and variety of the animals available. * * * In the comparative physiology of the blood, the corpuscles, proteids, and respiratory pigments of the blood of different animals are studied, together with the comparative physiology of blood clotting. The chief forms used are the starfish, sea-urchin, Scycotypus, lobster, Limulus, and the dogfish. In the comparative physiology of secretion the various mechanisms of secretion will be illustrated as far as possible by the glands of invertebrates."

As an example of the problems of *regeneration* mentioned above we may cite the following: "If a worm normally produces a head, a series of segments, and a tail, what will happen if you cut the worm in pieces and then graft the head on the tail end? Or a hermit crab, fitted into its conch shell, and well known to rapidly regenerate its large exposed claws, what will happen if you cut off one of the apparently useless hidden claws which have been lying for thousands of generations within the conch?" The purposive quality in living things, the apparent determination to overcome all obstacles and attain an end is best illustrated in the remarkable experiments of the above kind, in which Prof. T. H. Morgan has become a leader in this country. These have culminated in his recently published work, Regeneration, a hopeful and optimistic counterpart of Nordau's pessimistic volume upon human society. The moral of these experiments is briefly expressed in Hamlet's aphorism "There's a divinity that shapes our ends, rough hew them how we will," a moral so strong that quite a school of young natural philosophers in Germany are reviving the older teleological and vitalistic theory of living things as opposed to the chemical and mechanical theory.

[a] A tropism is the tendency shown by an organism to react in a definite way to certain external stimuli, as of sun-light (heliotropism), gravitation (geotropism), electricity (galvanotropism), etc.

Another line of research in the solution of which America, thanks chiefly to E. B. Wilson, Conklin, and Mead, is an acknowledged leader, is suggested by the following question: If a developing egg (for example, the minute and delicate little surface-floating egg of some sea-urchin) normally divides into two, four, eight, and ad infinitum cells to form the adult, what will happen if you shake these cells apart after the first, second, etc., cleavage?

The initial step is to study the undisturbed process of cell division through "cell lineage." The transformation of the simple fertilized egg cell is always accomplished by splitting into many cells, which ultimately constitute the various tissues. It is obviously a matter of great interest and importance to trace the lineage of the tissues backward toward the undivided egg. This has been done to such an extent that we can designate the particular cells that give rise to the outer covering of the body, to the nerves, alimentary canal, and to the reproductive and germ cells. Very early in the history of the embryo the future functional and structural regions are marked off, and there is a beginning of what Spencer termed the physiological division of labor. Some biologists are inclined to carry this back still further into the components of the egg itself.

One would suppose that any rude disturbance of this beautiful process would abruptly terminate life. Quite the contrary; the general answer to all such questions as the above being that the unexpected will happen. Out of the patient observation of the unexpected, however, is coming the rationale of the life processes.

The remarkable general result has been obtained that upon shaking apart the segments after the egg has divided into four or eight parts, these isolated cells do not die, but again subdivide and form a lot of twin or quadruplet individuals, as the case may be. In the early experiments of this kind by Wilson and others each separate cell produced a minute but entire individual. But when Crampton happened to repeat the experiment on certain snails' eggs, the main result was that only one-half or one-fourth of an embryo snail was produced. In sea-urchins, in which shaking also produced fractional animals, the missing fractions were supplied by regeneration—another very striking example of Hamlet's aphorism.

In 1900, Prof. Jacques Loeb announced the remarkable discovery that in starfishes and other forms, by suitable treatment with solutions, not only of various salts, but also of such substances as sugar and urea unfertilized eggs may give rise to swimming larvæ. This discovery, like most others of similar character, was the natural sequence of experiments which had started lines of thought in this direction. Richard Hertwig in 1896, in Germany, had shown that strychnine starts the eggs of sea-urchins on the course of development. And Morgan, between 1896 and 1900, at Woods Hole, had shown that the



INTERIOR VIEW OF MARINE BIOLOGICAL LABORATORY, WOODS HOLE, MASS.

unfertilized eggs of *Arbacia*, a sea-urchin, when treated with solutions of sodium and magnesium chlorides, would segment and advance into much later stages than those observed by Hertwig, though no swimming embryos were produced. Thus to Morgan and Loeb, of Woods Hole, belong a large share of the credit of what has been called one of the most epoch-making discoveries of modern times, that of artificial fertilization.

Parthenogenesis, or the development of a female egg without the access of a male element or spermatozoon, had long been known among various lower types of animals; instances are to be found in the bees, social wasps, *Bombyx psyche*, Daphnia, plant lice, and others. Here was a case of artificial parthenogenesis, and Loeb was led to compare these natural and artificial phenomena, reaching the conclusion that fertilization carries into the egg a catalytic substance which accelerates a process which would otherwise proceed too slowly. Thus fertilization, from having a purely vital aspect, assumes a chemico-physical aspect, and the hitherto mysterious phenomena of parthenogenesis finds a partial explanation.

In his discussion of this development without the male element, Loeb says it has an important bearing upon the theory of life phenomena:

> If we succeed in finding a substance which accelerates the process of cell division at the normal temperature, this will at the same time lead to a suppression or reduction of the antagonistic process that shortens life. It is not impossible that "natural death" is comparable to the situation on the mature egg after it leaves the ovary. Nature has shown us the way by which at this critical point death can be avoided in the case of the egg.

It is safe to prophesy that the bearing of these and similar discoveries on medicine and pathology will be no less important than the experiments of Pasteur on bacteria.

The effects of different solutions upon the development of the egg is illustrated by an experiment conducted by nature herself: *Branchippus stagnalis* is a fresh-water crustacean, which, if raised in concentrated salt solutions (salt lakes), becomes smaller, undergoes some other changes, and transforms into a species which has been known as *Artemia salina*,—a classic case of transformation under the action of external conditions, first observed by Schmankewitsch. This observer kept *Artemia* in salt water, which he constantly diluted by adding fresh water until at last it was perfectly fresh; the crustaceans had meanwhile gone through several generations, and had gradually so completely changed their characters that finally they acquired those of the genus *Branchippus*.

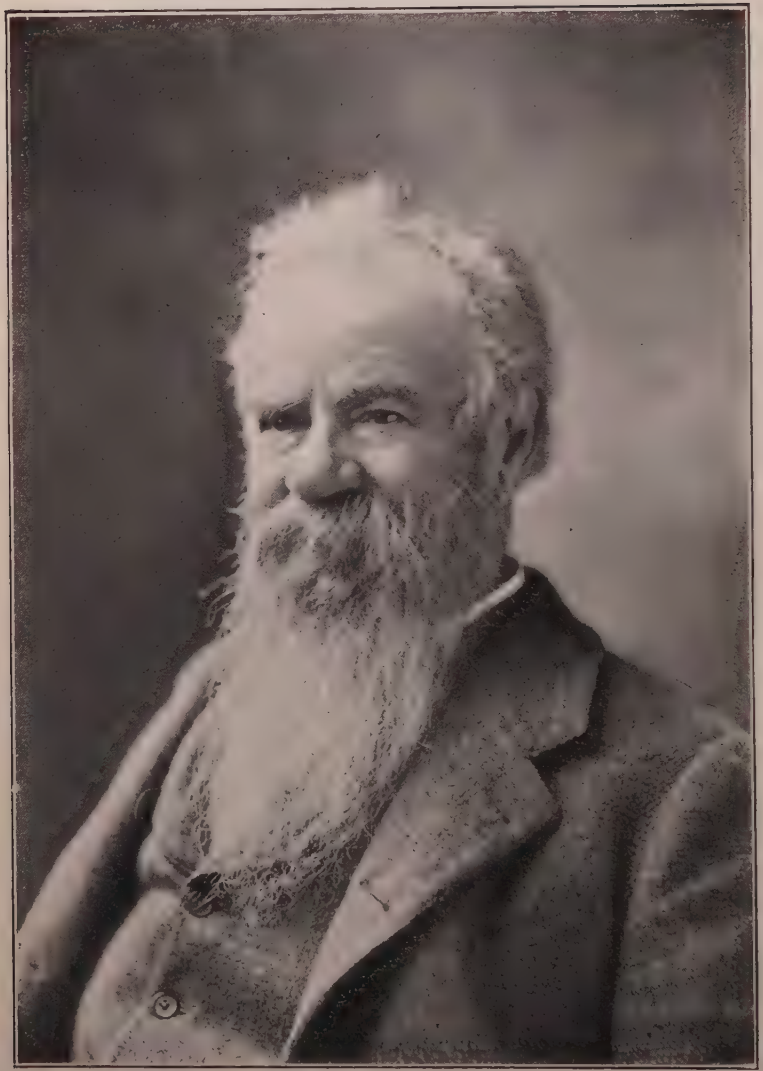
The artificial process has been erroneously spoken of in the press as "chemical" fertilization. The single fact that Dr. Albert Mathews has been able to initiate development by the shaking of the egg indicates

that artificial fertilization is as much physical as chemical. Mead, Conklin, and many others, following the Belgian, French, and German schools, had long been studying the internal changes in natural fertilization, and as a sequel to these discoveries are the recent researches and experiments of Prof. Edmund B. Wilson on the changes which go on in the egg after artificial fertilization. These were presented before the International Zoological Congress at Berlin and attracted much attention. They show that the unfertilized egg, by the addition of magnesium salts, is able to create a complete mechanism of cell division. But under this unaccustomed stimulus, in the words of Wilson, "they manifest a multitude of aberrations which constitute a veritable carnival of development, which one can hardly witness without a sense of amazement." These aberrations are of high interest on account of the side light they throw on many debated problems of normal cell function and structure.

The value of all these observations hinges, of course, upon the essential unity of protoplasm throughout the animal kingdom; as in Huxley's prophecy, whatever applies to the protoplasm of sea-urchins we may be sure applies in some degree to the protoplasm which constitutes the basis of human life.

The life and the social congress at Woods Hole are almost as varied as the problems investigated there. School teachers from all over the Union, students from the smaller inland colleges and the largest universities, young aspirants for the doctor's degree, older men of international reputation in botany, zoology, physiology, psychology, all come under the magnetism of the "M. B. L.," as it is familiarly known. Work is not too strenuous, it is tempered by the undercurrent of the feeling that, after all, this is summer vacation time and one must not be too serious. In fact, at Woods Hole, as with our English and continental scientific brethen, life is well balanced and altogether reasonable while no less productive.

Among the things evidently of supreme value in the modern university are: the traditions and history of the institution; its appropriate location and housing; the availability of the sources and instruments of knowledge; the presence of a cosmopolitan assemblage of the students and teachers of numerous sciences—all of which, we have seen, constitutes the charm of our "marine university."



JOHN WESLEY POWELL.

1834–1902.

JOHN WESLEY POWELL.[a]

By G. K. Gilbert.

John Wesley Powell was born March 24, 1834, at Mount Morris, N. Y. He died September 23, 1902, at his summer home in Haven, Me. He was married in 1862 to Emma Dean, of Detroit. His wife and daughter, an only child, survive him.

His parents were English, having reached this country only a few years before his birth. His father was a Methodist preacher and soon removed from New York, living successively in Ohio, Wisconsin, and Illinois. His father's occupation took him much from home, and upon the son, while yet a boy, devolved the duty of conducting the farm from which the family derived its principal support. Powell's early schooling was that ordinarily obtainable in a rural community. His later education was largely independent of schools, but he attended Illinois College, at Jacksonville, Ill., for a short time, and was at Oberlin College two years pursuing a special course. In early manhood he supported himself by teaching, being at the same time a hard student and pursuing natural history studies with enthusiasm. He traversed portions of Wisconsin, Illinois, Iowa, and Missouri on foot, collecting plants, shells, minerals, and fossils, and these collections brought him into relation with various colleges of Illinois. At the outbreak of the civil war he enlisted in the Twentieth Regiment of Illinois Volunteers, and abruptly changed the course of his studies to military science. His successive commissions ranged from second lieutenant to colonel, but the rank of major gave the title by which he was known colloquially in later years. His service was chiefly with artillery, but some of his most important work was of a character commonly assigned to engineer officers. In the battle of Shiloh he lost his right arm, and the resulting physical disability affected his life in important ways. On the one hand, the wounded arm caused him at various periods much pain, and thus weakened an exceptionally strong constitution. On the other, he was led in early manhood to employ an amanuensis, and the resulting freedom from the mechanical factor in writing was a distinct advantage to his literary work.

[a] Revised by the author from article published in Science, October 10, 1902.

At the close of the war he promptly returned to civil life, dropping the study of military science as abruptly as he had begun it. An attractive opportunity to enter political life was declined in favor of scientific work. He became professor of geology at Bloomington, Ill., and lecturer on geology at Normal, Ill. In 1867 he organized and led the first important geological excursion of American students, taking a party of 16 to the mountain region of Colorado. This was before the building of transcontinental railways, and the journey across the plains was long. He remained among the mountains as an explorer after the party had returned East, and in the following years organized a second expedition with geologic and geographic exploration and research as its chief objects. The necessary funds were furnished by various educational institutions in Illinois, and Congressional authority was obtained for supplying the party with provisions from the military posts of the West. His expedition wintered west of the Rocky Mountains in the valley of White River, and the long period thus spent in a permanent camp was occupied in the scientific study of Indians. In the following spring four boats were brought from Chicago to the point where the newly constructed Union Pacific Railway crossed Green River, and a party was organized for the exploration of the canyons of the Green and Colorado rivers. When this work was begun it was known that the rivers here descend in a distance of 700 to 1,000 miles through the vertical space of 5,000 feet, coursing most of the way between unscalable walls, but the nature of the rapids, cascades, and cataracts by which the water falls from the upper to the lower level was altogether unknown. The undertaking was therefore of phenomenal boldness and its successful accomplishment a dramatic triumph. It produced a strong impression on the public mind and gave Powell a national reputation which was afterwards of great service, although based on an adventurous episode by no means essential to his career as an investigator.

The voyage through the canyons was a reconnoissance in an unexplored area and led to the organization of a geographic and geologic survey, for which appropriation was asked and obtained from Congress, the work being initially placed under the supervision of the Smithsonian Institution. By the advice of Professor Henry, the gathering of ethnologic data was made a leading function of the organization. In 1869 a boat party began a second voyage through the canyons, the plan being to spend two years in their mapping, and land parties were at the same time organized to cooperate with them. The river was abandoned as a base of operations in the middle of the second season, but the land work continued, with progressive development of plan, for a period of ten years. About the middle of this period the study of the problem of the utilization of the arid region through irrigation and otherwise became a function of the organiza-

tion, and a special investigation was made of the water supply of the Territory of Utah.

Of parallel growth were the surveys developed under the initiative of Dr. Hayden, Clarence King, and Lieutenant Wheeler. Their functions were similar, and with the exception of the work by King, which had a definite limit, their ambitions included the exploration and survey of all the western domain of the United States. They thus became rivals, and there was need of reorganization. After unsuccessful efforts to arrange for the partition of the field and friendly cooperation between the different corps, Powell advocated their merging into a single bureau of the Interior Department, and it was largely through his initiative that the work was finally reorganized in 1879. The Powell, Hayden, and Wheeler surveys were abolished and the present United States Geological Survey created, Mr. King becoming by presidential appointment its first director. At the same time the Bureau of Ethnology was created to carry forward the ethnologic work, and of this Powell became director. The Geological Survey was made a bureau of the Interior Department, and the Bureau of Ethnology was attached to the Smithsonian Institution.

The study of water supply in relation to irrigation led to the conclusion that the land laws of the United States were ill adapted to the conditions obtaining in all the drier portions of the country, and Powell became much interested in the legislative problems thus arising. Partly at his instance a commission was appointed to codify the land laws and recommend such modifications as seemed to be required. Powell gave much of his time for two years to the work of this commission, and a comprehensive report was prepared, which, however, led to no legislation.

In 1881 Mr. King resigned the directorship of the Geological Survey, and Powell was immediately named as his successor. He retained the direction of the Bureau of Ethnology and conducted both bureaus until 1894, when he resigned from the Geological Survey. During his administration the work of the Survey was greatly enlarged, especially in its geographic branch, and the investigation of water supply with special reference to utilization for irrigation was added to its functions.

In the last years of his life Powell practically relinquished administrative responsibility, intrusting the management of the Bureau of Ethnology to his principal assistant, Mr. McGee, and devoting his time to personal studies, which passed gradually from anthropology into the fields of psychology and general philosophy.

In summarizing the results of his active life it is not easy to separate the product of his personal work from that which he accomplished through the organization of the work of others. He was extremely fertile in ideas, so fertile that it was quite impossible that he should

personally develop them all, and realizing this he gave freely to his collaborators. The work which he inspired and to which he contributed the most important creative elements, I believe to be at least as important as that for which his name stands directly responsible. As he always drew about him the best ability he could command, his assistants were not mere elaborators, but made also important original contributions, and the ideas which he gave the world through others are thus so merged and mingled with theirs that they can never be separated. If we count the inspiration of his colleagues as part of his work of organization, then the organization of researches may properly be placed first in the list of his contributions to the progress of science. Other terms of the list pertain to the fields of geology, physical and economic geography, anthropology, and philosophy.

The creation of the United States Geological Survey belonged to the logic of events and would undoubtedly have taken place within a few years without Powell's assistance, but his active advocacy hastened the change and his ideas had greater influence than those of any other individual in determining the mode of reconstruction of the national scientific work. He was so prominent as a promoter of reorganization that when it had been accomplished he felt that his motives might be impugned if he became a candidate for the directorship of the Survey, and he therefore declined to have his name presented. It is proper to add that the scheme of reorganization which he advocated was not adopted in full. His plan included the organization of three bureaus to conduct investigation in the fields of geology, geography, and ethnology, but Congress created only two bureaus, leaving geography without special provision. The work of geographic mapping was taken up by the Geological Survey as a means for providing base maps for the use of geologists, and thus the Survey has become a bureau of geography as well as geology.

Two years later, when Powell succeeded King in the administration of the Geological Survey, he found the subdivision of the work arranged largely on geographic lines. There were branch offices at Denver, Salt Lake City, and San Francisco, each in charge of a chief who directed the geologic and topographic work of a large district. For this classification Powell gradually substituted one based upon function, abolishing the districts and separate offices and creating divisions of topography, general geology, and economic geology, coordinate with divisions of paleontology, physics, and chemistry. A real or geographic classification was still used, but was subordinated to a subject classification.

Careful attention was given to the financial system of the Bureau, the machinery by which the public funds were paid out and accounted for, and the wisdom of this attention was afterwards fully justified. When in later years the affairs of the Survey were subjected to

unfriendly and searching investigation the accounts were found in such perfect condition as to elicit the highest praise of the Comptroller of the Treasury, to whom the results of the investigation were finally referred. The reputation of the Survey for good business methods inspired the confidence of legislators and led them to provide for the growth of the Bureau, not only by the increase of appropriations for existing functions, but through the gradual enlargement of function. The most important single addition to its duties was that of studying the water supply of the country with reference to various economic problems.

Except for the original suggestion or instruction by Professor Henry, and except for the votes of funds by Congress, the Bureau of Ethnology may be regarded as Powell's creation. Work on American ethnology had previously been discursive, unorganized, and to a large extent diletanti. He gave to it definite purposes conformable to high scientific standards, and personally trained its corps of investigators. To men who had previously interested themselves in the study of Indians he gave new methods and a new point of view, and he succeeded in diverting to ethnology men already trained in scientific methods by work in other fields of research. He realized, as perhaps few had realized before him, that the point of view of the savage is essentially different from that of the civilized man, that just as his music can not be recorded in the notation of civilized music, just as his words can not be written with the English alphabet, so the structure of his language transcends the formulæ of Aryan grammars, and his philosophy and social organization follow lines unknown to the European. He also realized most fully that the savage is the embryo of the man of highest culture, and that the study of savagery is therefore a fundamental contribution to the broadest study of humanity. With these ideas he informed his ethnologic corps, and in consequence of them the organization of the Bureau marks the most important epoch in American ethnology.

The same personal influence extended to the work of the Anthropological Society of Washington. Over the proceedings of this society Powell presided for many years, taking part in all its discussions and making it his special function to point out the bearing and relation of each communication to the greater problems and broader aspects of the science. As the bureau was and is a laboratory of ethnology, devoted to the study and record of the character and culture of the fading tribes of North America, so the society, including the same group of students, was and is an arena for the discussion of the broader science of anthropology. I but echo the general sentiment of those students in saying that the high intellectual and scientific plane on which the work of this society is conducted is a result, direct and cumulative, of Powell's influence and example.

Before turning to Powell's direct contributions to science, mention should be made of his studies in biology. In early manhood he was an assiduous collector of plants, fresh-water shells, and reptiles, and this work was accompanied by studies in distribution, but the results of such studies do not constitute a contribution to botany and zoology. The work was properly a part of his education, a training in the art of observation, which bore fruit only when his attention was turned to other branches.

His contributions to geology include a certain amount of descriptive work. He published the stratigraphy, structure, and part of the areal geology of the Colorado plateaus and the Uinta Mountains. In connection with the field studies in these districts he developed a new classification of mountains, by structure and genesis; a structural classification of dislocations; a classification of valleys; and a genetic classification of drainage systems. His classification of drainage recognized three modes of genesis, of which two were new. With the novel ideas involved in the terms "superimposed drainage" and "antecedent drainage" were associated the broader idea that the physical history of a region might be read in part from a study of its drainage system in relation to its rock structure. Another broad idea, that since the degradation of the land is limited downward by the level of the standing water which receives its drainage, the types of land sculpture throughout a drainage area are conditioned by this limit, was formulated by means of the word "base level." These two ideas, gradually developed by a younger generation of students, are the fundamental principles of a new subscience of geology sometimes called geomorphology, or physiographic geology.

The scientific study of the arid lands of our Western domain in relation to human industries practically began with Powell. Early in his governmental work he issued a volume on the lands of the arid region, and he continued their discussion in one way or another for twenty years, setting forth the physical conditions associated with aridity, the paroxysmal character of rainfall, the dependence of arable lowlands on the rainfall and snowfall of uplands, and the generous response of the vegetation of arid regions to the artificial application of water. Emphasizing the necessity of irrigation to successful agriculture, he pointed out the need of conserving storm waters by artificial reservoirs, the need of applying new principles in legislation for the regulation of water rights, and the need of a new system of laws for the control of title in arid lands. These ideas when first advanced were the subject of hostile criticism because they antagonized current opinions as to the availability of our Western domain for settlement; but he afterwards found himself part of a general movement for the intelligent development of the West, a movement whose latest achievement is the so-called reclamation law.

He pointed out also that our land laws did not permit the lean pasture lands of the West to be acquired by private owners in tracts large enough for economic management, and that overstocking and periodic disasters were the logical results of public ownership; and his ideas as to remedial legislation were embodied in the unheeded report to the Public Lands Commission.

In descriptive ethnology Powell's published contributions are meager in comparison with his body of observations and notes. They are comprised in a magazine article on the Moki, an essay on the Wyandot, and a few myths, chiefly Shoshonian, introduced in various writings for illustrative purposes. In his "Introduction to the Study of Indian Languages" he gives instructions for American ethnologic observation, covering not only the subject of language, but arts, institutions, and mythology. Other writings belong more properly to anthropology, and deal with its broader principles. In a series of essays, designed as chapters of a manual of anthropology but actually published as occasional addresses and never assembled, he points out the lines of evolution in the various fields of human thought and activity, philosophic, linguistic, esthetic, social, and industrial. The ground covered by these essays is so broad that a brief summary is impossible. They include the ideas which have directed the work of the Bureau of Ethnology, and they include also much which has found no immediate application, belonging to fields of thought as yet untouched by others. As to their ultimate value future generations must decide, but they stand nearly or quite unique as a comprehensive body of philosophic thought founded on the comparison of aboriginal with advanced culture.

In latter years attention was gradually turned from anthropology to psychology and the fundamental concepts of natural philosophy. His interest in these subjects began in early manhood, and they are briefly touched in various writings; but he gave the last eight years of his life almost wholly to their study. Two books were written and a third planned. "Truth and Error," which appeared in 1899, treats of matter, motion, and consciousness as related to the external universe or the field of fact. "Good and Evil," printed as a series of essays in The Anthropologist with the intention of eventual assemblage in book form, treats of the same factors as related to humanity or to welfare. The field of the emotions was assigned to the third volume. His philosophy was also embodied in a series of poems, of which only one has received publication.

In much of his scientific writing Powell's style is terse to a fault. Usually he is satisfied with the simplest statement of his conclusions. Sometimes he adds illustrations. Only rarely does he explain them by setting forth their premises. It has thus happened that some of his earlier work, though eventually recognized as of high importance,

was at first either not appreciated or misunderstood. The value of his anthropologic philosophy, though now widely appreciated, was recognized but slowly outside the sphere of his personal influence. His philosophic writings belong to a field in which thought has ever found language inadequate, and are for the present, so far as may be judged from the review of "Truth and Error," largely misunderstood. Admitting myself to be of those who fail to understand much of his philosophy, I do not therefore condemn it as worthless, for in other fields of his thought events have proved that he was not visionary, but merely in advance of his time.

To the nation he is known as an intrepid explorer, to a wide public as a conspicuous and cogent advocate of reform in the laws affecting the development of the arid West, to geologists as a pioneer in a new province of interpretation and the chief organizer of a great engine of research, to anthropologists as a leader in philosophic thought and the founder, in America, of the new régime.



Rudolf Virchow

RUDOLPH VIRCHOW, 1821–1902.

By Oscar Israel.[a]

Germany of the latter half of the nineteenth century is so entirely different in almost every respect from Germany of the period which preceded it that it is difficult to realize the actual transition of the one into the other. The bustling political and economic movements of to-day, and the general uplifting of the whole condition of culture, were preceded by a period when either an apathetic or a friendly idealic life might be called forth according to local conditions. And yet the two decades immediately preceding the year 1850 were by no means a dead time, for although but little apparent upon the surface still there was a deep and regular, untiring and fresh movement in those days, the activity of work. A work for culture was being completed which had consciously for its purpose the awakening and progress of the nation. It is no accident that the generation which then grew up lived to see greater changes in their fatherland than any that had preceded. Pure-minded German science, untroubled by chauvinistic jealousy, has never failed to recognize the mighty intellectual stimulus which she has ofttimes owed to foreign lands; but she ever recalls with just pride the purely national development which has gone on unceasingly from the time of her own intellectual giants of the eighteenth century. This movement matured its best representatives in the years of external pressure, for it was in these very periods of stress that intellectual activity found the time to ripen. Living on in the traditions of the undying classics, the German school formed the men to whom we owe the Germany of the present. One by one they pass away—these landmarks of the Germanic culture of the nineteenth century who brought it to before unknown excellence—and now, in his turn, is Rudolf Virchow departed from this life.

Rudolf Ludwig Karl Virchow was born on October 13, 1821, in the town of Schievelbein, in further Pommerania. Much of interest regarding his childhood is disclosed in the account which he himself

[a] Translated, by permission of author and publishers, from the "Deutsche Rundschau" of December, 1902.

set down in the Easter vacation of 1839. This first literary production deserves in more than one respect the publication awarded to it by the Prussian minister of education in the eightieth year of its author's age, for the reader can see depicted in the child's inner life many of the germs of character which unmistakably developed in the work of later years.

The youth of 17 expresses deep gratitude for the loving care of his father, the treasurer of the town, who was enabled to meet with helpfulness all the difficulties which rose up to oppose the eager humanistic ambitions of the son. Reading and writing were learned from the father; and at the town school and with the clergyman of the parish he continued his preparation for college. But the way was not made easy for him. The methods of instruction of the rector must have been quite peculiar. "He so overrated my knowledge that he gave over the instruction of some beginners in Latin to me, so that I myself forgot what little I had learned." The young teacher was at that time but 11 years old. Private instruction with the preacher, Gantzkow, remedied these defects, however, so that the happy student entered the third class of the gymnasium at Köslin on May 1, 1835.

In the publication of the minister of education there is a portrait of the boy at about 4 years of age which shows a friendly child face with large, wide-opened eyes, the corners of the mouth a little drooping, and the expression one of interested attention. The presence of certain anatomical peculiarities which appear in later photographs, indicate that the portrait must have been well drawn. By the aid of this likeness the reader can picture to himself the student at the gymnasium who discloses in his diary his thoughtful spirit, and in whom the extraordinary eagerness for knowledge, the sharp self-criticism, and the love of truth have left the impress of an early maturity.

The undesirable influences of unworthy fellow-students upon his impressionable and vivacious temperament during the second year were overcome as a senior. He was certainly an exception among young men of his age in that he realized what threatened him. He writes "I can at least assure you that in the pursuit of pleasure I have always sought to keep within proper bounds, and I believe I have generally succeeded, at least so far that my studies have not suffered, nor even has my health been impaired. The good spirit which rules among my classmates of the senior year has aided me in this endeavor."

His favorite studies were the natural sciences, history, and geography, as well as the ancient classic writings of Cicero, Sallust, and among the Greeks, Sophocles. To these he devoted his spare hours, but at the same time he did not neglect to improve himself by reading French and German authors. The highly gifted lad early showed a strong tendency to reflection, and soon acquired a solidly grounded and copious store of knowledge, which enabled the young student to

bring to his studies a ripe understanding and a critical discrimination. Far better grounded in the older tongues, especially the Latin, than our modern students, Rudolph Virchow retained through life secure mastery of them, and in his later years he exhibited a keen sensitiveness to the barbarisms of which the present scientific generation is not guiltless. In the year 1883 he gave an earnest exhortation to his fellow-workers and the readers of his periodical[a] in regard to this matter, and still later he again uttered a word in favor of a good terminology.[b]

At Easter time, 1839, at the age of 17 years and 6 months, Rudolph Virchow passed first among eight students at the examination, and in the autumn entered as a student of medicine at the Königlich medizinisch-chirurgische Friedrich Wilhelm's Institut at Berlin. (This was the so-called Pepiniere, now Kaiser Wilhelm's Academie für das militärärztliche Bildungswesen.) He went through the regular course of the "Eleven," but found time for private research. It is an interesting illustration of his habit of mind that the future military surgeon heard the lectures of Friedrich Rückert's colleague upon Arabic poetry.

April 1, 1843, he was appointed "Charité-Chirurgus," which corresponds with the present position of assistant physician. He entered immediately into practical work which brought up a host of suggestions calculated to develop the germinating ideas of his student days. He felt that he must still learn, and that a thorough scientific education was a necessity for him, and was, therefore, not content merely to follow on with his comrades, but chose for himself his own course.

The one who exercised the most influence upon the student was Johannes Müller, the many-sided master, preeminent in each of the several lines of work which he undertook. He early became Virchow's ideal, and so he remained. In the masterly memorial address which he delivered[c] after the untimely death of Müller, July 24, 1858, Virchow gave fitting utterance of the deep feelings of gratitude which he ever cherished toward the master. Appreciating objectively the extent of Müller's talents and achievements, he raised for him an undying memorial. Eminent as an anatomist, zoologist, and physiologist, Müller was not less eminent in pathology; but the pupil who was to carry forward his work to unimagined further development crowns him who had destroyed the false philosophy of Schelling with "the laurel of the true natural philosopher of the real flesh and blood." He sketched with firm hand Müller's development from almost mystical tendencies to the true spirit of exact scientific research, and attributed to "Nature and Goethe" a powerful influence on Müller's intellectual

[a] Barbarisms in medical language. Archiv f. pathologische Anatomie u. Physiologie u. f. klinische Medizin, vol. 91, pp. 1–11.

[b] New names and new ideas in pathology. Berliner klinische Wochenschrift, 1900, No. 1.

[c] Johannes Müller. Eine Gedächtnisrede. Berlin, 1858.

development, perhaps recalling his own experiences, for Virchow's own thoughts had grown up in Goethe's school.

It fell to Virchow also to deliver a memorial address for the other master, who, next to Müller, had exerted the greatest influence upon him. This was for Johann Lukas Schönlein, and was delivered at the Berlin University in 1865.[a] In both these addresses we find many things indicative of Virchow's own course of growth, but still more numerous are the interesting historical references. Particularly valuable are notes on the development of medicine as a science in the first half of the nineteenth century. While yet a student Virchow had aided in this, and before the end of his student days he engaged actively in research along these lines. On October 21, 1843, the degree of doctor was conferred upon him by Johannes Müller (then dean of the faculty of medicine) for his work on the inflammation of the cornea (De rheumate præsertim corneæ). Rudolph Virchow remained for a long time assistant at the charity hospital, but on March 20, 1846, he passed the state examination, with the added commendatory words "very good" and "as operative surgeon." The time preceding this, however, had been a very important period of his life, for he had begun his career as a student of nature. More and more he occupied himself with the scientific treatment of the anatomic material of the hospital, assisting the demonstrator of anatomy, Robert Froriep, who, with just respect for his ability, shared many operations with him. At the solicitation of this discriminating friend, the general physician, Grimm, appointed Virchow to the position of assistant at the dissecting laboratory of the hospital in the year 1844. His gratitude to Froriep is suitably expressed in the preface of a volume of collected works[b] dedicated to his master and friend, and doing honor to both master and pupil. Almost ten years after he himself had become in his turn demonstrator of anatomy at the hospital, this volume, in which his scattered and often difficultly accessible papers are brought together, was dedicated by Virchow to the man who had guided his first steps in the line of scientific inquiry.

On May 11, 1846, not two months after passing the state examination, Virchow became acting demonstrator of anatomy at the hospital in the place of Froriep, who had retired, although the definitive appointment was made conditional on his separation from the military connection. The impression had been current that Virchow's departure from the Pepiniere was not voluntary, but in consequence of differences there; but, in reality, the case was exactly the reverse. His departure was accompanied by the cabinet order of April 6, 1847, which expressed in a most gracious way the appreciation of his scientific labors and released him from some years further military service

[a] Gedächtnisrede auf Johann Lukas Schönlein. Berlin, 1865.

[b] Collected writings on the science of medicine. Frankfurt a. m., 1856.

for which he was still liable.[a] Not yet 26 years of age, Virchow had now the opportunity of developing his powers in his own way.

The position of demonstrator of anatomy had grown up from a rather slender beginning. The somewhat infrequent opportunities of confirming and broadening diagnosis by post-mortem examination had been almost exclusively confined, during the eighteenth century and the first third of the nineteenth, to the physicians to whom the care of the patient had been committed. Only of late had the need become apparent of physicians specially prepared for this purpose. The first demonstrator who had been attached to the hospital staff was P. Phöbus, but he remained little more than a year in this capacity and had resigned because he could not defend himself from the occasional encroachments of a military surgeon. He was succeeded by Robert Froriep, who was appointed, on December 22, 1831, as "Demonstrator, illustrator, and curator of pathological preparations at the Royal Charity Hospital." There were set apart for his use only a room and bed chamber, and it was not till 1834 that upon a detailed memorial of Froriep's to the ministry, in which he stated clearly and at considerable length the pressing need of it, that a good microscope was procured. A single attending nurse, Frau Vogelgesang, was, at the time Virchow succeeded Froriep, the most important personage in the administration of the little realm. In the occasional correspondence relating to the purchase of improvements or to other internal arrangements her signature was never lacking, but appeared together with those of the physicians and hospital director. The considerable reputation which "Madam Vogelgesang" enjoyed far beyond the boundaries of Germany was due to her great skill in dissecting operations.[b] At first a voluntary assistant, Virchow was soon intrusted by the management of the charity hospital with the chemical and microscopic investigations necessary for the sick wards. These duties, now divided in all great hospitals between special laboratories with trained personnel, were very extensive and laborious, but with characteristic energy and inspired by an illustrious example, Virchow soon showed a complete command of the situation. He saw in a combination of chemical with anatomical researches the possibility of attaining an object of capital importance—namely, the creation of a pathologic physiology as the result of prearranged studies in anatomy and pathology, combined with experimental pathology and chemical experience. This experimentally founded science he sought to substitute for the confused speculation then ruling German medical practice.

The intense activity of the young savant in the dissecting room of

[a] Two years later Helmholtz, who had attained the rank of staff surgeon in the military service, received his discharge in the same form.

[b] See Perogow. Life questions. Diary of an old physician. From the Russian, by August Fischer, Stuttgart, 1894, p. 403f.

the charity hospital was rewarded in 1845 by the great success of his investigation on "white blood."[a] Continued studies led him to the description of a hitherto unknown form of disease to which he later gave the name of Leucocythæmia. Meanwhile Virchow had already become lecturer on pathologic anatomy, and had given practical courses on the cadaver, in which he developed the technique of dissection, and which later formed the basis of the Prussian "Regulations for the practice of medical jurisprudence in examinations of the human cadaver." Other countries framed regulations modeled after these, so that the practices here promulgated have become to considerable degree the standards for the whole world.

Virchow early became the center of a circle of congenial friends, of whom the more prominent were Ludwig Franke, the great clinical physician of that day, Rudolf Leubuscher, and especially Benno Reinhardt. The latter was of a reserved, quiet, studious nature, but still capable of being stirred to passionate outbreaks in the warmth of scientific enthusiasm, and stood with Virchow in the eager search for truth and in revolt against the authoritative beliefs and the artificial systems which then prevailed in the medical science.[b] From this friendly alliance grew up that powerful instrument in the warfare for the new experimental science of medicine, the "Archiv für pathologic Anatomie und Physiologie und fur klinische Medizin." "Had it not been for Müller's Archiv," writes Virchow later, "we should scarcely yet have known in Germany how a scientific journal should be conducted."[c] But Müller's journal occupied another field, being chiefly concerned with normal anatomy and physiology, so that pathology found only occasional place in it. The "Archiv für physiologische Heilkunde," published in south Germany, as well as the "Zeitschrift für rationelle Medizin," were so one-sided in their editing that the friends were refused a place in these columns and found themselves obliged to found a journal of their own. Virchow recalled with gratitude how in these circumstances the publisher, George Reimer, came their aid; who, as he says, "had the courage to place his means at the disposal of two almost unknown young men." Their prospectus appearing with the first number in April, 1847, is signed: Dr. Rudolf Virchow, Prosektor beim Charite-Krankenhause, Dr. Benno Reinhardt, Practischer Arzt.

A short notice by G. Reimer dated Berlin, April 6, 1847, fixes the price of the volume of three numbers at three German dollars. This journal has now reached 170 volumes. The first volume, of whose

[a] Foriep's Neue Notizen. No. 780. November, 1845. Reprinted in Virchow's Gesammelte Abhandlungen zur wissenschaftlichen Medizin. Frankfurt a. M., 1856, pp. 149–163.

[b] Archiv, vol. 4, p. 541.

[c] Archiv, vol. 100, p. 2.

fourteen articles Virchow contributed eight, appeared in the course of the year 1847, the second in 1849. Both editors had been carried away by the political storm of 1848, and thus the regular progress of their work was interrupted, but, notwithstanding this, Virchow and Leubuscher started in the interim the Medizinische Reform, a weekly periodical, whose first number appeared July 10, 1848, and whose last number, 52, was dated June 29, 1849. It was a fighting sheet, which had for its object general reform in the care of health.

This work for reform was the main result of the journey to Upper Silesia, which Virchow had begun with the Geheimen Obermedizinalrat, Barez, on February 20, 1847, at the behest of the Prussian ministry, to study the epidemic of typhus fever which had broken out there in the summer of 1846. He returned to Berlin on March 10, Barez having preceded him on February 29. This journey is become famous from Virchow's report, which soon after appeared under the title, "Mitteilungen über die in Oberschlesian herschende Typhusepidemie."[a] Virchow had been charged by the authorities with "the investigation of the scientific significance of the nature of the epidemic." But besides a pathologic, anatomic, and clinical investigation of sick and dead, which would have satisfied any other investigator, the report contains much more. He gives a monograph on the conditions of society in Upper Silesia in which the whole social and educational history of the province is set forth, and makes proposals for the treatment of the contagion. Painstaking accuracy, warmhearted sympathy and courageous frankness are everywhere in evidence. Virchow recognized that the common medicines and dietetic regulations suitable to sporadic cases were of little avail against the epidemic; and that the endemic disease owed its dangerous spreading character to the deplorable social conditions; the ignorance of people and authorities alike favoring the diffusion of contagious matter, and all contributing to diminish the resistance of individuals to contagion. Only through radical political and social reform, he maintained, could there come an effectual remedy. The same matter which the Paris Académie de Médecine had brought to the attention of the Egyptian Government he laid before the authorities in the following terms: "The logical answer to the question of the prevention in future of conditions similar to those we now see in Upper Silesia is therefore easy, and is simply this: Education, with her two daughters, freedom and prosperity." This measure which he here advocates led to the development of a thoroughly democratic programme. In his formulation of it, there were, to be sure, some fantastic features resulting from the disturbed condition of the times, but in the struggle of the next ten years not a little of it was adopted. The present beneficent

[a] Archiv, vol. 2, Nos. 1 and 2, pp. 143–322, 1847. Also Berlin, 1848.

operation of medical legislation is the immediate consequence of the fiery exhortations of the young charity hospital demonstrator, and later on he took a leading part as medical expert and as parliamentarian in the drafting of this legislation.

It was at this time that the "Medizinische Reform" began the battle for the health of the people. Questions of legislation and conditions were chiefly treated by R. Leubuscher and S. Neumann, while education and medical science were in the hands of Virchow. All these problems were connected with the political background, and the conditions out of which they grew and which were necessary factors of their solution were never lost sight of. In the article with the title "Conclusion," in No. 52 of the periodical, there is a note of resignation. Like the other contents of the last numbers, it is unsigned, but is unquestionably the work of Virchow, who had carried the whole weight of responsibility since the first of the year. The article begins with a verse from Ecclesiastes, and this also appears in the concluding paragraph, which is a solemn pledge sincerely adhered to by Virchow in the remaining fifty-three years of his life:

"We recognize therefore only the question of the healthful daily existence and daily bread for the people, and dedicate ourselves to making the broadest preparations with which the battle can be fought to ultimate success. The medical reform which we have advocated was a reform of science and of society. We have outlined its principles, and they will force their own way without the aid of this organ, but every moment shall find us working for them and ready to do battle for them. We do not change the thing, but only the place. It would be not only useless but foolish to sow young seed among stones or to plant it in the earth in winter. 'To everything there is a season, and a time to every purpose under the heaven.'"

Virchow was thus so deeply connected with political questions, even though not occupying himself with the minor details, but only with the main principles, that his pay and allowances were suspended for a short time in the spring of 1849 on account of his activity as an agitator, but still with all this his scientific work never wholly ceased. The epidemic of cholera in that unlucky year furnished him rich material for his investigations.

Soon after the above-mentioned orders and their partial repeal (the free lodging in the hospital was not restored to him) Virchow was called to the University of Würzburg, and he gladly accepted this opportunity of freeing himself from a situation which had become so unpleasant. In Würzburg began that rapid rise to the same degree of leadership in the world which he already enjoyed in a more limited circle. Before leaving Berlin he published in the autumn of 1849 his famous philosophic statement, "Die Einheitsbestrebungen in der wissenschaftlichen Medizin,"[a] in which he gave proof to friend and foe

[a] Berlin, 1849, and "Gesammelte Abhandlungen" Frankfurt, 1856.

alike that he had deliberately chosen his mission and never "either at the dissecting table or behind the microscope, at the sick bed or in public life, in the manifoldness of details forgotten the unity of principles." The "law of the unity of human existence and its consequences" he had treated in a number of sketches entitled, Man, Life, Medicine, Sickness, and Contagion, and later he placed these essays, enlarged by illuminating notes, at the beginning of his collected works. It is not possible in a brief account to go deeply into the "Einheitsbestrebungen," which embraces the connection of medical research with the most fundamental things of human existence. Much that now is accepted as self-evident stands here in the center of the field about which the battle between the contending schools of science raged. Questions of belief, the doctrine of vital force, which with that of the spontaneous generation is now long since laid aside, and the system of medicine which had bound medical thought in hard and fast dogmatism, all find thoughtful and for the time keen and courageous criticism. There never appears any semblance of personal animosity, however sharp the criticism, and all the positions are taken wholly on objective grounds.

There has recently been a widespread discussion as to the position of Virchow in relation to fundamental religious questions, and many utterances have been attributed to him whose cynicism would make it apparent that they could never have come from him. The position which he firmly held is completely given in the following passage from his "Einheitsbestrebungen:"

"There can not be any issue between faith and science, for science and faith mutually exclude one another; not in the sense that the one renders the other impossible, or vice versa, but rather that so far as science extends faith does not exist, and faith begins where science leaves off. It can not be denied that beyond this limit there may be real objects to be embraced by faith. It is therefore not the object of science to destroy faith, but rather to define the boundaries to which knowledge extends, and within these to establish a uniform system."

He strongly attacked the materialism of Karl Vogt, whose assaults upon his own tolerant position toward faith are unjustifiable. Though opposing dogmatism where it came in his way, he much more strongly opposed materialism, for he believed it to be more dangerous than the views of the church or those of the idealist, but nevertheless he declined as a student of nature to follow with this latter party upon transcendental ground. While desiring himself to associate with science the strongest objectivity, he yet showed in his later years unreserved respect for such degrees of subjectivity as did not spring from unexcusable violation of scientific truth. He is even charged with inconsistency because of his energetic opposition to Ernst Haeckel at the scientific convocation at Munich in 1877. Haeckel had

demanded[a] the introduction of his monistic teaching in the schools. Virchow declined to teach these problematic matters as results of science, for there rose up against it not only the scrupulous regard of the scientist for certainty, but also his revolt against any measure of compulsion in matters of belief. He remarked at the time privately to the writer of these lines that Haeckel forgot that he (Virchow) as the representative of the people must be considerate for the feelings of those of a different belief.

In Würzburg a time of most diligent scientific activity for Virchow occupied the period of political paralysis following the outbreak of 1848. His fame was securely founded upon his Berlin investigations, and especially upon the fearless and successful attack which he made upon the then prevailing teaching of Rokitansky upon crasis. The investigations begun in Berlin on disorders of the blood and the blood vessels and on parenchymatous inflammation, whose first germs had appeared in his thesis, besides other investigations of the biology of the cells and tissues were completed in Würzburg. Here also Virchow devoted himself with great success to researches in experimental pathology, to which he gave a place with pathologic anatomy and chemical investigation. His greatest achievement in this field is the explanation of the processes of thombosis and embolism (stoppage of the blood vessels by clotted blood and the importation of such obstructing masses by the circulation). Such conditions might, as he showed, arise from the cause of wounds. He sharply distinguished between the consequences of infectious thrombosis and the beneficial ones, and this and much of his other work was of great importance in leading to better understanding of the infectious diseases. These investigations, with those already mentioned upon the fever epidemic in Upper Silesia, and his studies in 1852 on the famine in Spessert,[b] gave the impetus to Virchow's work on epidemics, and with it the remarkable revolution of the practice of medicine in Prussia and throughout Germany in the next ten years.

Still another field in which Virchow's work was to be of the greatest value, he first entered while at Würzburg. His first publications in this field were entitled: "Untersuchung über den Cretinismus, namentlich in Franken und über pathologische Schädelformen."[c] and "Über die Verbreitung des Cretinismus in Unterfranken."[d] In these Vir-

[a] Amtlicher Bericht der fünfzigsten Versammlung deutscher Naturforscher und Ärzte München 1877, pp. 75–77.

[b] Die Not im Spessert. Eine medizinische-geographische historische Skizze. Verhandlungen der medizinische-physikalischen Gesellschaft in Würzburg, 1852.

[c] Presented in the Würzburg physikalisch-medizinische Gesellschaft on May 24 and June 21, 1851. Verhandlungen, Bd. 2, p. 230, reprinted in collected works, p. 891.

[d] Presented as above on May 9 and November 13, 1852. Verhandlungen, Bd. 3, p. 247, and collected works, p. 939.

chow commenced that great series of anthropological papers in the strict sense, from which grew up the modern combination of Anthropology, Ethnology, and Archæology. But principally he occupied himself at this time with special studies of the most varied pathologic anatomic and chemical problems. They all had for their common aim to provide an impregnable material basis for theoretical deductions through the strict application of the scientific method of exact description of observed conditions. Most of this work appeared in the "Archiv" and in the "Verhandlungen der Würzburger physikalisch-medizinischen Gesellschaft," which latter Virchow had founded shortly after his call to Würzburg together with Albert Kölliker and Kiwisch. He also undertook a great literary work in the editing of the "Handbuch der speziellen Pathologie und Therapie," in whose first volume he contributed a long article on "general disturbances of alimination," together with an appendix treating of parasitic plants and animals. For the other parts of this great work, which included from 1854 to 1876 six large volumes, he gained the cooperation of a number of eminent contributors. Since then many similar compilations have appeared, having for their object an encyclopædic presentation of the knowledge and science of medicine up to the time of their publication. All these have in Virchow's handbook their precurser and example, but it is here impossible to discuss even its main features.

In the autumn of 1856 Virchow accepted a call to Berlin, which thus led him back to the original scene of his labors, but now under quite altered conditions. He found himself at the head of an institute founded on the work which he had done at Würzburg and specially devoted to the interests of pathologic anatomy, experimental pathology, and particularly to chemical researches. To be sure the building which had been hastily and economically erected by the hospital directors, Horn and Esse, was not up to his requirements. There were necessary many changes and many renovations, one even as late as 1873 which greatly extended its usefulness but not without seriously disturbing the work. Particularly the increase of the collection of pathologic anatomic preparations suffered greatly and it cost its author great trouble to again bring it up with other branches of the work. But he succeeded in creating a center for pathologic investigations, which with all its branches, among them the instruction of young students, was the forerunner and example of all the similar institutions now to be found not only in Germany but in all civilized lands throughout the world. It would not be too much to say that within his institute pulsed the heart of science which sent the ideas of the master inspiring and broadening through the labors of his pupils over the whole circuit of the earth. Here Virchow's genius and wonderful forcefulness found their full greatness and his life work took on its lasting proportions.

A year before Virchow left Würzburg he had coined the word "cellular-pathology" which briefly designates the nature of his life work.[a] The researches of the previous years, in particular those upon the connective tissues, had gradually brought to light the principle which was to occupy the place before shared by pathology and general medicine. But it was not till February, March, and April of 1858 that Virchow delivered before an audience composed chiefly of the medical men of Berlin the twenty lectures which he published in the same year under the title "Cellular pathology as founded upon the physiology and pathology of tissues."[b]

When Virchow commenced his scientific career, the art of medicine was under the stamp of different systems, pathology being dominated by Rokitansky, the great pathological anatomist of Vienna. He was the founder of the so-called Viennese school of pathology and had given to it a doctrine of dyscrasia, constructed like its predecessors on a priori rather than experimental grounds. Although excellent in the descriptions of diseased conditions and well grounded in its anatomy, as Virchow readily admitted, yet the third volume of Rokitansky's handbook of pathologic anatomy completely ignored the method of exact research. He remained in the error of speculation, reviving the old humoral pathology in his theory, and attributing all diseases to impurity of the blood, from which they were communicated to the solid parts of the body. According to this doctrine these latter were practically excluded from pathologic considerations, while on the other hand under the rule of the doctrines of solid pathology the opposite had been the case. Rokitansky had made little use of the microscope, an instrument first introduced in pathologic studies near the end of the eighteenth century by the great Frenchman Bichat and used increasingly in Virchow's program with the effect, as he says,[c] "of bringing the path of general medicine at least three hundred times as close to the natural course of procedure." The figure, of course, refers to the magnifying power then employed. We now use powers at least three times as high, but a power of three hundred would suffice readily to disclose the elements of animal structure which correspond to the generally much larger cells of plants.

Moreover, the discoveries of Schleiden and Schwann had come to recognition, and the anatomists began to think of cells, although the conception of the origin of single cells expressed in Schwann's "Theory of free cell building" was by no means the true one. According to this theory the cells arose from a condensation of matter, or blastema,

[a] Archiv, vol. 8, pp. 3–39.

[b] Berlin 1858. The second edition appeared in 1859, the third with many additions in 1861, the fourth rewritten and greatly enlarged in 1871.

[c] On the reform of pathologic and therapeutic demonstration by microscopic investigations. Archiv, vol. 1, p. 255.

named for its connection with the cells the "cytoblast." This substance was supposed to form first the cell nucleus and then the inclosing sheath or cell membrane, after which a new germ collected between the nucleus and cell membrane. The current ideas of life were shaped entirely upon the theory of generatio æquivoca, and for all forms of life not possessing special generative organs parentless generation had to be assumed. This view has long since been overthrown; for the ferments by Eilhard Mitscherlich, and for the vegetable parasites principally by Louis Pasteur; while in the attack upon the theory of spontaneous generation of animal parasites Rudolf Virchow participated with Rudolf Leukart in clearing up the development of the trichinæ. Spontaneous generation was assumed in the theory of the formation of the cell from the blastema, and the subsequent formation of a new cell involved a second process of the same kind. According to the prevailing idea there were in the bodies of men and animals a group of tissues nearly destitute of cells, but Virchow's proof of the presence of cells in the bones and cartilage, as well as of their persistent presence in the connective tissues, dealt a heavy blow to the theory of free-cell formation, and this theory collapsed completely after his researches on the connective tissue and parenchymatous inflammation. That which had been known as the cytoblast, a more or less regular substance lying between the cells, was recognized as lifeless. In young, growing, and particularly in embryonic tissues, the cells were found to be more exclusively cellular the younger the tissue, and only after the tissues reached a considerable age did the intercellular masses appear. These latter, according to Virchow's theory, were not simply dependent for their formation but for their very substance upon the cells, which are the only living parts, and which are formed, as experiments showed, only from living cells already present. Virchow, usually an enemy to formulæ, coined for this relationship the expression *omnis cellula a cellula.*

By numerous tests of the constitution and behavior of diseased tissues he showed that the action of disease consists in the alteration of cells, and that the life of the individual depends upon the life of his cells. Nourishment, specific functions (work), and growth are all regular actions of cells, while disease is an anomalous cell activity.

Virchow, aided by all the medical investigations which had been stimulated by his experimental school of thought, continued to build up his pathology upon the foundations which his discoveries in cellular pathology had laid, and the cellular principle has been the basis of the greatest advances of the last decade. Indeed, it would not be too much to say that the whole modern science of biology is built upon the law of the cell succession, and it is this which has assured to Virchow's work its undying value beyond the boundaries of strictly medical science. To be sure there has come forward occasionally the view

that the life processes do not reside in the cell as a whole, but are proper to certain smaller parts, the nature of whose activity determines disease or health, but these views have not been maintained. Biology is cellular, and medical thought remains cellular in its pathology.

We have hitherto been tracing the course of Virchow's life and noting the principal achievements, which stand like milestones to mark his advance. Continuing in this way, we must now take note of one of his greatest works, namely, "Die krankhaften Geschwülste."[a] It is, to be sure, incomplete, for only 25 of the proposed 30 lectures composing it appeared in the two and a half volumes published. But what Virchow has set down in these three books remains to-day, after almost forty years, an indispensable reference work and a guide to those working in this subject. The exemplification of the scientific principle of proceeding to the understanding of a thing from an investigation of its development, the deep thorough discussion of a wealth of confirmed experimental material, all this combined with the brilliant presentation, have caused the "Onkologie" to take rank as the greatest of Virchow's works.

Just as he chose the genetic method in seeking the explanation of the significance of all discoveries by an inquiry into the nature of their origin, so also Virchow did not neglect to employ the same method to investigate the causes of phenomena. He studied the ætiology of diseases in the widest sense, and his investigations of the parasitic diseases, the causation of affections by the action of animal or vegetable parasites within the tissues, formed a considerable part of his ætiological researches. It is not possible to enter upon them within the limits of this article, but in the interest of truth it should be stated that at no time in his life did Virchow mistake the importance of plant forms of disease germs, and never opposed any movements of thought leading in this direction. Thus, in 1858, we find in the Archiv[b] "Beiträge zur Lehre von den bei Menschen vorkommenden pflanzlichen Parasiten." He gives here, among other observations, the first good description of fungus diseases of the lungs and bronchial tubes (*Broncho- and Pneumonomykosis aspergillina* and *Pn. sarcinica*).

His theories furnished the ground work for the later rise of bacteriology. It was supposed by many that there was an outspoken opposition, or at least a distrust, on Virchow's part of the revolution in bacteriological methods which was going on under the leadership of Robert Koch. Nothing could be more incorrect. Virchow, who had himself done much in the interest of a scientific explanation of the many facts which he had brought to light, had pointed out the direction which this branch of general pathology was to take, and gladly recognized all contributions to the science. It was only against the

[a] Berlin, 1863–1867.

[b] Archiv, vol. 9, pp. 557–593.

recognition of unproved assumptions, against one-sided investigations and conceptions, and against premature generalizations that he protested. The real advances of ætiological knowledge he sought continually, with all the weight of his influence, to promote and to bring to general recognition.

Similar imputations have been current in regard to his position relative to another disputed question, namely, that of Darwinism. He had numerous objections to some of the single propositions of the Darwinian theory; particularly as the result of his own observations he recognized more fully than Darwin the pathologic side of the question of heredity. According to Virchow the rise of a variety of a transmissible character presupposes a "deviation from the type and therefore a pathologic (though by no means a diseased) condition of the progenitor."[a] The rôle of atavism he was inclined to belittle as one of a number of unproved assumptions, but he was a no less firm believer in transformism than Darwin and Johann Friedrich Meckel, whose great service to the theory of descent Virchow repeatedly and properly emphasized.[b]

How could a man fail to accept Darwinism who was so influenced in his intellectual development by Goethe[c] and under whose hand modern anthropology has become what it now is, the scientific study of man. Starting with somatic anthropology, in natural expansion of his field of work, in 1866 he began his investigations in prehistoric archæology. At first he occupied himself with the primitive history of his Pommeranian home region, to which as a student he had already devoted some historical studies that appeared in the "Baltischen Studien" and the "Pommerschen Volksblatt." From this the field of his investigations extended over the whole earth. Contributions from every quarter, some gathered in long journeys through Europe, western Asia and Egypt, which he took during the vacations, and more collected by the army of scientific discoverers who in the last forty years have penetrated to all parts of the earth, furnished him with his material. He himself grasped the spade and introduced the scientific method in archæological investigation. It is impossible even to mention here all his more important investigations and publications in this and related fields during the four busy decades which followed. Only a few can be touched upon, among them the inquiry concerning the origin of the human race and its dispersion in the course of ages. He published numerous articles filled with rich material in the "Zeitschrift für Ethnologie," largely conducted by him, and in the "Verhandlungen der Berliner Gesellschaft für Anthropology, Ethnologie und

[a] Archiv, vol. 103, p. 205.

[b] Archiv, vol. 103, p. 10.

[c] See "Goethe als Naturforscher und in besonderer Beziehung zu Schiller. Eine Rede mit Erläuterungen. Berlin, 1861.

Urgeschichte," of which he was almost sole editor. These communications embrace, besides more than a thousand shorter articles, a series of extensive independent publications of the highest importance. Among these latter can be mentioned here only the third volume of the magnificent publication by Stübel and Reiss on the burial field at Ancon and the great work Crania ethnica Americana which appeared in commemoration of the discovery of America by Columbus.

Virchow devoted himself to ethnographic studies no less than to other branches of anthropology, and here he became a center to which the material streamed in from all sides, and from which went forth suggestion, criticism, and energetic assistance. This never-idle man did not disdain to teach travelers schooled in other lines of investigation the anthropometric methods; and indeed he found time for everything, and never left a piece of work to others that he could possibly undertake himself. Thus, for example, for ten years following its inception by him in 1876, he worked up alone the data recorded in German schools as to the color of the eyes, the hair, and the skin which has proved of such value for the knowledge of the different branches of the German race. He has reduced the ethnology of his homeland to a practically complete system, and his work in this line has fortunately been put in shape for popular appreciation in the Museum für deutsche Volkstrachten.

Perhaps one of his greatest services to the science was that he persuaded the visionary dilletante Heinrich Schliemann to undertake with Dörpfeld's help a rationally conducted excavation at Troy, and, still more, that he succeeded in bringing the treasure digger back with his unique and invaluable discoveries to the fatherland. They have been placed permanently in the Schliemann hall of the Museum für Völkerkunde where they will remain as an enduring monument to Rudolf Virchow as well.

But investigating and collecting were not his only activities, for all this time he remained in the first rank of academic teachers, expounding not only the facts, but the philosophy of medical science. The method he employed of teaching pathology was quite his own, but has become the example, not only for Germany, but for other civilized lands. He has discussed the teaching of pathology in weighty papers,[a] and, indeed, on several occasions entered into the discussion of general academic instruction and its extension. He was no inflexible supporter of the old classic system of education, for in his Rectorates address he remarked that linguistic studies might be very well supplanted from a pedagogical point of view "by the golden triad mathematics, philosophy, and the natural sciences," but still from consideration of the

[a] Über den Unterricht in der pathologischen Anatomie, "Klinische Jahrbücher," vol. 2, pp. 75–100, and in W. Lexis, "Die deutschen Universitäten;" R. Virchow, Die pathologische Anatomie, pp. 241–261, Berlin, 1893.

sources of our Western culture he could not subscribe to a complete displacement of classic studies by the modern practical subjects.

The great pathological and anatomical collections, which are the results of the manifold labors of his long life, must stand in the front rank for purposes of instruction in his own branch of science. Although much of the material there assembled is primarily adapted to purposes of pure scientific inquiry, still the objects were gathered by him chiefly with a view to their educational value. It must, therefore, have been a great satisfaction to him to see in the newly erected pathologic museum a worthy depository for this unequaled collection. In the arrangement of this museum it is not only the directly interested scientific circle, but quite as much the popular audience whose instruction is considered. He formed a special easily accessible exhibit to illustrate to the widest circles the knowledge most valuable to the general welfare, just as in his younger days he had not disdained to endeavor to awaken in the popular mind by the simplest ways and appreciation for the value of science. It would require a special article to tell how much work he spent on the objects of this collection, but an idea of the immensity of it can be gathered from the fact that about 23,000 preparations in the pathologic museum bear labels written by Rudolf Virchow. These labels give in the most concise terms the chief result of an often extensive investigation devoted to each single object.

In all the problems to whose investigation he devoted himself, in all practical matters which came to his attention, and in every branch of science with which Rudolf Virchow engaged he kept in mind the relations of the subject to the public life. If at the first attack upon a new problem it was the love of knowledge for its own sake which spurred him on, yet in every case the wider application appealed at length to the warm heart and ideal loving mind that kept in view in all that he did the good of his fellow-men. He put away each little egoistic striving and devoted his whole strength to the work, never hesitating to take up matters which hardly required the powers of a Rudolf Virchow to accomplish them. He knew that even in our German fatherland, penetrated as it is by Kant's philosophy, not all men possess that degree of trustworthiness which he desired to see in all, but which in men of science he held indispensable. Whenever he failed of finding exactly the man to do a piece of work he undertook it himself where any particular degree of responsibility rested upon him in the matter. A deep inbred modesty kept him from any feeling of vanity, but it is easy to understand why he, the deep philosopher and the minute observer, after he became acquainted with the real situation entered into the political arena. With the keen vision of the student of nature he recognized the real cause of public ill-health could only be removed by a general uplifting of public intelligence, and only

thus could further political degeneration be prevented. His journey of investigation in Upper Silesia gave him the first incentive to his political activity. Although not naturally combative, but rather contemplative and conciliatory, he did not lack in personal courage and self-forgetfulness, and entered into political action without fear of the consequences of his outspoken thinking, and the more readily, perhaps, when his actions cost him dear. It was thus he entered at first into the political agitation and speedily became the representative of the people. The characteristics which distinguished his scientific work he placed at the service of the common weal, so that his enemies could but admit in him an uncommon fullness of knowledge and a sure memory, a never satiated desire and capacity for work, and, finally, the thorough conscienciousness and unassailable veracity of the man of science. To be sure he was no political seer, and the practicability of many of his recommendations was disproved in the trial, but on the other hand it is certain that he was in many points in the right and that it was his scientific habit of thought and the thoroughness of his methods of work which, in the thorny paths of the nonprofessional parliamentarian as also in municipal life, yielded those results which have been of such incalculable value to the hygiene of Berlin.

Rudolf Virchow always strove after results, but was little concerned for the mere outward signs of them. The presence of the battle steeled his courage and sharpened his desire. Small vanity was wholly foreign to him, and he could detect a flatterer at the first meeting. He was receptive only to such recognition as indicated in itself that he was rightly understood, and he made use of such recognition for his own guidance, for it showed him the measure of the usefulness of his work for the general good better than, in his modesty, he could himself have estimated it. It was in this spirit that both in politics and in his scientific work he accepted the homage which flowed to him more and more as, in the course of the decades, his work widened. He is celebrated in foreign lands no less than in Germany, and he appreciated the national significance of his honors and refrained from putting them off that the prestige of his fatherland might not lack. The more Rudolf Virchow became the critical controlling center of German science, as evidenced by his official standing and in particular in his conduct of the great "Berliner Medizinischen Gesellschaft," the "Berliner Gesellschaft für Anthropologie, Ethnologie und Urgeschichte," his leading place in German and international scientific congresses,[a] and

[a] With his tact and cleverness he chose for the subjects of his addresses in foreign lands actual or historical presentations from the national tradition of the country in question. Thus in England he spoke of Glisson in "Über den Wert des pathologischen Experimentes." In this address he supported the English medical profession in its battle against the antivivisectionists. In Italy, among others, he chose the theme "Morgagni und der anatomische Gedanke" (address before the eleventh international medical congress at Rome, 1894).

his place as an educator, the more he achieved cosmopolitan greatness. At this time when he has but just ceased his heretofore unbroken labors it can not yet be appreciated how great he had become and how much science lost by his death.

In this short sketch only the main points can be indicated; a later time must furnish the historian who shall truly interpret Rudolf Virchow and his epoch. Then, when all the documentary material now scattered in contemporary periodicals and in correspondence and notices throughout the world is brought together, an adequate view can be taken of the splendid combination of human qualities which made the foundation of Rudolf Virchow's greatness.[a]

His spirit will ever reside in the fundamental revolution which he brought about in medical science and practice, and his work will go on in the new paths he opened in all departments of science which he entered, and in the methods of investigation which he so unweariedly taught. Herein rests the tradition which remains with his disciples, and this is their weapon to use for the full freedom of learning and objective teaching.

[a] See O. Israel, "Zu Rudolf Virchow's Achtzigstem Geburtstage," Ärztliche Monatschrift, 1901, heft 10.

INDEX.

Page.

Abbot, C. G., galvanometer improvements by 25
recent astronomical events 101
report on Astrophysical Observatory 85–96
Abbott, W. L., explorations by 35
collections from 31, 32, 102
Absolute zero, history of 207–240
Absorption of atmosphere and solar envelope 86, 88, 90
Actinium, discovery of 199
Adams, Robert, jr., member of Museum building committee 3
Regent of the Institution x, xi, 2, 4
Adler, Cyrus, librarian's report 97–99
Administration, Secretary's report on 5
Aerodrome, Langley 111, 122
Aerodynamics, Langley's experiments in 12, 100
Aeronautical experiments by Wilbur Wright 133–148
progress, by Baden-Powell 121–131
societies 122
Aeronautics, Langley on 7, 103
Aeroplane, advantages of 127
Aflalo, F. G., some private zoos 103
Africa, geographical knowledge of 359
African pygmies 479–491
Agassiz, marine laboratory founded by 625
Air, atmospheric, conductivity of gases of 11
"boiling," in astronomical work 26
currents at varying altitudes, study of 10
liquid 219
physical properties of, researches in 9
resistance of, researches by Canovetti 8, 9
upper, composition of 230
uniform flow of, through tubes 9
Airship, Santos Dumont's 103
Airships, Baden-Powell on 121
Alaska, Bogoslof volcanoes 102
development of, dependent on reindeer 621
Indian tribes of 43
Laplanders in 616
preservation of marine animals of 103
reindeer in 613–623
zoological station proposed in 23
Alloys, intestinal activity of 412
microscopic study of 411
researches in 298

Page.
Alphabet, origin of, in the Orient 519
Alpine tunnels, by Fox 103
American Ethnology, appropriation for 6
estimate for 7
expenditures for xx
American Historical Association, report of 14, 108
Amonton's air thermometer 210
Andaman Islands, Abbott collection from 102
people of 463, 465
Anderson, Tempest, report on eruption of the Soufrière 309–330, 342, 348
Anderson, John 626
Andrews bequest xii
Angell, James B., Regent of the Institution x, xi, 4
Antarctic explorations, progress in 352
voyage of Belgica 102
Anthony, William A., trans-Atlantic telephoning 101
Anthropoid apes, craniology of 431–449
Anthropological collections received by Museum 31
studies in California 104
Ants, termites or mixed, Haviland on 103
Ape-like men of Africa 480
Apes, anthropoid, craniology of 431
size of skull of 433
Appropriations, disbursement of xvii
statement of xvii, liii, 6
Aquarium, need of, in Zoological Park 24
Arabic numerals, origin of 515
Archæological collections received by Museum 32
work of Bureau of Ethnology 39–57
Rudolph Virchow 656
Archæopteryx, discovery of 590, 591
Arctic expedition of Robert Stein 31
Arctowski, Henryck, Antarctic explorations 102
Arcturus, heat of 159
Argon, rays of 232
Arid lands, Powell on reclamation of 634, 638
Arizona, archæological collections from 32
Arrhenius, Svante, researches by 179, 235
Ashmead, W. H 33, 35
Asia, geographical progress in 355
Assuân dam on the Nile 531
Astronomical events, recent, by C. G. Abbot 101
photographs, improvements in 152
Astronomy, comets' tails, the corona, and the aurora borealis 179
stellar evolution 149
Astrophysical instruments at Yerkes Observatory 151
Observatory, annals of 85, 107
appropriation for xliii, lvi, 6
estimate for 7
exhibit at Buffalo iii
expenditures for xliii
letters commending work of 4
property of 85

Page.
Astrophysical Observatory, report by Abbot on 85–96
Secretary's report on 24
Senate document on 14
study of "boiling" of telescopic image 194
Atmosphere, absorption of 86, 88
limit of height of 231
transparency of 89
upper, composition of 230
exploration with kites 101
study of 10
Atmospheric air, conductivity of gases in 11
Electricity, Journal of 10
researches in 190
transmission of light by 89
Atoms, bodies smaller than 101, 179
Aurora borealis, cathode rays and 190
height of 233
nature of 187
periodicity of 189
relation to sun spots 188
result of electricity 231
study of, by John Cox 179
theory of 187
Auroral rays, number of 232
Auroras, Dewar on nature of 229
Austin, O. P 623
Automobile races 103
Avery fund xii
Avery, Julia N xii
Babylonian culture in the West 509
Bacteria, effect of cold on 239
Bacteriological studies of Professor Virchow 654
Baden-Powell, B. F. S., recent aeronautical progress 121–131
Baird, Spencer F., established Woods Hole laboratory 626
statue proposed for 16
Baker, Benjamin 532
Baker, Frank, report on Zoological Park 73–84
Ball, Sir Robert, commends Astrophysical Observatory 4, 24, 85
Balloons, navigable, Baden-Powell on 122
Banks, Nathan 106
Baoussé-Roussé explorations 451–458
Barium, radio-activity of 205
Barlow's logograph 246
Barton's air ship 125
Barus, Carl, Hodgkins grant to 8
ionized air experiments 8, 12, 100
structure of the nucleus 8
Baskerville, Charles, literature of zirconium 100
Basketry, directions for collecting 107
Bateson, W., problems of heredity and their solution 559–580
Baum, H. M 457
Becker's theory of rock crystallization 307
Becquerel, Henri, radio-activity of matter 197–206

Page.

Bell and Kidder fund xviii
Bell, Alexander Graham, favors bringing of Smithson's remains to America .. xiv, 3
phonograph improvements by 251
member of Executive Committee x
Regent of the Institution x, xi, 4
Benedict, James E 104
Benton, Elbert J 56
Berliner, Solomon 75
Bertholf, Lieut. Ellsworth P 615, 620, 623
Bevier, Louis, research in nature of vowels 9
Bezzi, M 36
Bibliography, chemical 100
spectroscope 100
Binny, A. J 431
Biological discoveries by Professor Loeb 630
laboratory at Woods Hole 625
papers in Museum Proceedings 104
researches by telephotography 9
Biology, number of animal species 582
morphological method in 581
Bird, Henry, collection from 32
Birds, fossil, progress in study of 589, 591
generic names, 1890 to 1900 107
lists of collections of 105, 107
Middle and North American 37, 107
Board of Regents, meeting of xi–xvi, 2, 4
members of x, 2, 4
Boas, Franz 42, 44, 52, 53, 102, 108
Bodies smaller than atoms, by Thomson 101
Bogoslof volcanoes, by Merriam 102
Bohio dam on Panama Canal 546
"Boiling" effect on solar image 26, 95, 193
Bolometer, invention of 25
precision and minute work of 25
Bolton, H. C., bibliography of chemistry 100
chemical societies of nineteenth century 100
Bonney, T. G 348
Book printing, origin of 525
Boomerangs, by G. T. Walker 102
Borchgrevink, C. E., Martinique disaster 348
Borneo, native tribes of 463
Botanical experiments in hybridization 563
Boule, Marcelin 451
Boulton, Bliss & Dallet, courtesies by 75
Bourdeau, L 393
Bowdish, B. S 32, 35
Bowditch, Charles P 54
Boyle, Robert, observations in low temperatures 208
Brain, function of lobes of 434
relation of man's and ape's 431
Branly, Dr., electrical researches by 264
Branly coherer, description of 265
Braun's experiments in low temperatures 211

Page.
Brockett, Paul 98
Brogger, Professor, study of rocks by 304
Bronze Age, skulls of man of 445
Brown, J. Crosby, collection from 31
Brown, John W., bibliography of manganese 100
Brownian movement, phenomenon of 408
Bruce, Miner W 623
Brute bodies, movement of particles in 406
Buffalo Exposition 16, 37
True's report on 110–115
Buildings, National Museum, improvements in 29
plans for new liv
Secretary's report on 5
Bumpus, Professor 626
Bureau of American Ethnology, appropriations for lv, 6
estimates for 7
exhibit at Buffalo 111
expenditures for xx
explorations at Lansing, Kansas 458
Henry suggests 637
publications of 14, 108
report of acting director 39–57
Secretary's report on 20
Burr, William H., Panama route for ship canal 537–557
Busch, August 75–107
Bush, George 439
Butterflies, American 106
Buysman, M 36
Call, Dr. Samuel J 620
Calvin, Samuel 455, 458
Camels, American origin of 585
Canal, Panama, history of project 537
Canovetti, C., air resistance researches 8
Hodgkins grant to 9
Capron, Rand, on auroral rays 232
Carnegie, Andrew, letter from xv, 3
letter to xv, 4
Carnegie Institution, foundation of 3
secretary of Smithsonian a member of the trustees xv, 3
Cartailhac, M., discoveries by 451, 452
Carter, W. H., Chinese guns from 32
Catalogue of scientific literature 15, 99
Cathode rays, auroræ and 190
Dastre on 101
from radio-active bodies 202
Caudell, A. N 33, 35
Ceramic art in China 104
Cell activity, Virchow's studies of 653
lineage, study of 630
Cellular pathology, Virchow's studies in 652
Chamberlain, L. T 34
Chamberlain, R. V 105, 107
Chamberlin, T. C., on Lansing remains 455

Page.
Chanute, O., on gliding-machine experiments 126, 133
Charleston Exposition 16, 37
Chase, Julia N xii
Chemical composition of living and brute matter 403
rocks 303
constitution of crystals 417
relation of form to 419
fertilization 631
societies of nineteenth century 100
Chemistry, bibliographies of 100
Children's room in Smithsonian 102
Chimpanzee, brain of 434
Chinese ceramic art 104
guns, collection of 31
printing, history of 525
Choffat, Paul 36
Chromosphere of the sun 161
Chronophotography, by Doctor Marey 101
Church, J. R., the Martinique disaster 348
Clark, A. Howard, editor's report by 100–109
Clark, Alvan G 153
Clark, Charles M., commercial telpherage 275–286
Clark, H. L 33
Clarke, C. A., shells from 33
Clayton, H. H., on Martinique disaster 348
Clerk-Maxwell's theory of light 263
Cloud formation, aurorœ and 190
Clouds, height of 231
Cockerell, T. D. A 104
Cockrell, Senator F. M., member of Museum building committee 3
Regent of the Institution x, xi, 4
Cocos Island, shells from 33
Cold, and absolute zero, history of 207–240
effect on living organisms 239
experiments with 208
Colonial Dames, collection from 31
Color photography, by Herschel 101
Colors of star, changes in 162
Comets' tails, Herschel's researches on 183
Kepler on form of 177
pressure of light on 180
the corona, and aurora borealis 179–192
Compass, ship's, origin of 520
Concannon, Martin 455
Congo forest, pygmies of 479
Consciousness in brute bodies 397
Contributions to knowledge, Secretary's report on 12
Coquillet, D. W 105
Coral, natural history of 609–612
Corona 160, 184, 234
study of, by John Cox 179
Corpuscles, minute size of 179
Cosmical clouds, condensation of 158
Cosmozeans, hypothesis of 40

Page.
Cox, John, comets' tails, the corona, and the aurora borealis 179–192
Cox, W. V., resignation of 30, 114
Craig, Oscar J 75
Crania, paleolithic, in Europe 443
Craniology of man and anthropoid apes 431–449
Crete, excavations at 102
Cromagnon race of men 442
Crosby, F. W 35
Crustacea, morphological study of 597
Crystalline germs, dimensions of 426
particle, character of 418
Crystallization of rocks, researches in 306
Crystals, living bodies and 417
nutrition in 422
mutilation and redintegration of 420
organization of 418
sowing of 425
Cuba, collections from 32, 35
Culin, Stewart 47
Cullom, Senator S. M., member of Museum building committee 3
Regent of the Institution x, xi, 4
Cunningham, D. J 434
Curie, M. and Mme., researches in radio-active matter by 199
Curtis, George C., on West Indian volcanoes 348
Dall, W. H 33, 104, 106
preservation of marine animals of Northwest coast 103
Darwinism, Virchow's belief in 655
Dassett, J. H., on St. Vincent volcano 348
Dastre, A., life of matter 393–429
salt and its physiological uses 103
the new radiations 101
Wright's experiments
Daughters of the American Revolution 14, 31, 109
Dean, Bashford, Egyptian fishes from 33
Debierne, M., uranium researches by 206
de Bradsky's balloon 122
Deckert, E., on Martinique disaster 348
De Leon, Perry M 75
De Mier, J. R., collections by 32
de Olea, Serverians 36
de Peyster, John Watts, Napoleon library from 15, 98
Devereaux, Ryan, collection from 31
De Vries, mutation theory of 103, 562
Dewar, James, Hodgkins special medal awarded to 10
on history of cold and the absolute zero 207–240
solid hydrogen 101
Diamonds in America, by Hobbs 102
Diller, J. S., on volcanic rocks of Martinique 348
Dinosaurs, F. A. Lucas on 103
morphological study of 591
Dinsmore, Hugh A., member of Museum building committee 3
Regent of the Institution x, xi, 2, 4
Discovery of the future, by Wells 375–392
Dixon, Roland B 43, 53

Page.
Doan, Martha, literature of thallium 100
Dohrn, Doctor 11, 625
Dolmens of Ireland 445
Dorsey, George A 44
on Lansing human remains 455
Draper, Henry C., cited 194
Dubois, Eugene, on Java skull 437
Durocher on formation of volcanic rocks 302
Dust particles, time required to settle 181
Dwarf negroes in Africa 483, 487
Malay Peninsula 463
West Indies 491
Dwarfs and gnomes of folklore 486
Dyar, H. G 33, 35
Earthquakes at St. Vincent and Martinique 311
Earth's atmosphere, transparency of 89
interior, meager knowledge of 347
Earthworms, progress in study of 582
Edinger, Ludwig, anatomy of nervous system 434
Edison's phonograph 251
Editor's report 100–109
Educational museum, Goode's definition of 18
Egypt, fossil animals in 586
irrigation in 531
Egyptian printing, origin of 526
Ekman, Sven 36
Electric discharges in sun's atmosphere 235
oscillations, telegraphy by 264
properties of bodies at low temperatures 237
storms relative to temperature 231
waves, demonstration of 263
utilization of 263
velocity of 263
Electrical displays at Mont Pelée 346
transportation of material 275–286
Electricity, atmospheric, researches in 190
Electrolysis, particles moved by 412
Electro-magnetic theory of light 180
Elephant house in Zoological Park 23, 74
Ellesmere Land, collections from 31
Elster and Geitel, researches by 205
Embryology, comparative 628
researches in 10
Emery, Matthew Gault, death of 27
Entomology, papers on 106, 107
Errara, Léo 393
Eskimo, value of reindeer to 614
Establishment, Smithsonian, members of IX, 1
Estimates for fiscal year 1903 7
Ether and gravitational matter, by Kelvin 101
vibrations, velocity of 263
Ethnological collections received by Museum 31
work of Bureau of Ethnology 21, 39–57
Major Powell 637

Page.
Evans, Arthur J., palace of Minos 102
Evans, Admiral R. D., swords of 31
Evans, Sir John 436, 445
Everette, Willis E 43
Evolution of petrological ideas 287–308
Executive committee, report of xvii–li
Experimental phonetics, by McKendrick 241–259
Explorations, Bureau of Ethnology 41
National Museum 34
Secretary's report on 12
Exposition, Buffalo 16
report on 110–115
Charleston 16
Louisiana Purchase 16
Expositions, Museum's participation in 37
Falconer, J. D., volcanic dust from West Indies 348
Farrington, Oliver C., on meteorites 101
Fellenberg, E. von 36
Ferris, J. H., shells from 33
Fewkes, J. W 42, 48, 108
Filipino swords, collection of 31
Finances, Buffalo Exposition 115
executive committee's report on xvii
Secretary's report on 5–7
Firefly, study of light of 96, 100
Fire-walk ceremony in Tahiti 102
Fish Commission station at Woods Hole 626
Fishes, collections received by National Museum 33
descriptions of 104, 105, 106, 107
fossil, colossal species of 593
progress in study of 592
recent, morphological study of 593
Fitzmorris, Maurice 532
Fletcher, Alice C 43, 54
Flett, J. S., on West Indian volcanoes 348
report on eruption of the Soufrière 309–330
Flight of birds, Baden-Powell on 124
theory of 134
Flower, Sir William, death of 436
Flügel, Felix 62, 69
Flying cage in Zoological Park 23, 74
machines, Baden-Powell on 122
balancing of 135
engines for 133
obstructions to success with 134
possibilities of 128
Foods of American Indians 40
Foreign agents, list of 68
Forest destruction, Pinchot and Merriam on 102
Fossil animals, discoveries of 583
birds and reptiles, progress in study of 590
fishes, morphological study of 592
human remains, near Lansing 455–462
invertebrata, morphological study of 600

Page.
Fossil man in France 451
remains with human implements 21
Fossils, descriptions of 106
Fouqué, Professor, researches by 298
Fournier, Henri, automobile races 103
Fowke, Gerard 43, 455
Fowle, F. E 91
Fox, Francis, great Alpine tunnels 103
Freezing mixtures, experiments with 208
Freshfield, Douglas, explorations by 356
Frobenius, L 36
Froriep, Robert 644
Frye, William P xi, 2, 4
Fuller, Melville W., Chancellor of the Institution x, xi, 4
member of Smithsonian Establishment ix, 2
Future, discovery of the 375–392
Gage, Lyman J., resignation of 1
Galpin, F. W 36
Galton, Francis, improvement of human breed 102
on laws of heredity 561
Galvanometer, Abbot's improvements in 91
sensitiveness of 92
Gandoger, Michael 36
Gann, Thomas 108
Gardiner, Edward G 626
Garrison, George P 56
Gases, in the sun, condition of 174
liquefaction of 215
Gates, Peter C 32, 35
Gatschet, Albert S 42, 53
Gaudry, Albert, new human type 451
Geare, R. I., list of National Museum publications 37, 107
Gegenschein, nature of 187
Geitel and Elster, researches by 205
Gems in National Museum 104
Geographical education, progress in 372
history, study of 353
knowledge, progress of 351–373
surveys, importance of 362
terminology 371
Geological additions to Museum 34
Survey, United States, organization of 635
theories, development of 288
Geology, progress in study of 287
Germs, crystalline, dimensions of 426
Gheen, Stephen 75
Gibbs, Willard, researches by 216
Giesel, M., researches in radio-active preparations by 199, 200
Gilbert, G. K., biography of J. W. Powell 633, 640
Gilbert, N. E 96
Gill, De Lancey 43, 44, 57
Glacial man in America 461
Europe 431

Page.
Glaciers, South American 357
Glazebrook, R. T., National Physical Laboratory 102
Gliding machine experiments 133–148
Goding, F. W 75
Gokteik bridge, by Willey 103
"Good Seeing," by S. P. Langley 193, 195
Goode, G. Brown, ceramic collection of 31
U. S. Fish Commissioner 626
Gordon, R. H., explosive force of volcanoes 348
Granite, theories of origin of 291
Gravitation, effect on stellar evolution 158
studies in, by Poynting 101
Gray, Elisha, apparatus used by 32
member of executive committee x
Gray, George, Regent of the Institution x, xi, 4
Gray's harmonic system of wire telegraphy 270
Greatest flying creature, by Langley 103
Gregory, W. K., marine university at Woods Hole 625–632
Griffon, Ed 393
Grosvenor, Gilbert H., reindeer in Alaska 613–623
Grotto of La Mouthe, pictures in 102
Guam, and its people, by W. E. Safford 493–508
agriculture at 502, 505
aboriginal inhabitants of 498
Guillaume, Ch. Ed 393
Gunpowder, origin of 520
Habel, Simeon, bequest of xvii, 6
Haddon, A. C 36, 443
Haeckel, Ernst 649
Haida Indians, language of 42
Hale, George E., commends Astrophysical Observatory 4
stellar evolution in light of recent research 149–163
Hall, Anne S., presents desk and quadrant used by Capt. C. F. Hall 32
Hall, W. S 434
Halm, J., a new solar theory 165–176
Hamilton, James, bequest of xvii, 6
Hamilton, William 623
Hammer, William J., the telephonograph 101
Hargrave's flying machine 122, 127
Harkins, J. N., collection from 31
Harris, William T 615
Harrison, Frederic 388
Hartmann's experiment with metals 414
Haviland, G. D., on termites 103
Hawaiian Islands, insects from 33
Hawks, E. L., collection from 31
Haworth, Erasmus 455
Hay, John, member of Smithsonian Establishment ix, 2
Hay, Robert 35
Healy, Capt. M. A., reindeer brought to Alaska by 615
Heat, lowest degree of 211
nature of 208
stellar, measurement of 159

Page.
Heierli, J., collection from 32
Heilprin, Angelo, on Mont Pelée eruption 339, 348
Helium, liquid 221, 226
Helmholtz, Professor 645
theory on contraction of solar mass 166
theory of vowel sounds 255
Henderson, J. B., member of executive committee x
Regent of the Institution x, xi, 4
report of permanent committee xii
Henry, Joseph 14
suggests Bureau of Ethnology 637
wireless telegraph experiments 262
Herbarium, National Museum 7
Heredity, Bateson on 559–580
problems of 628
Herring, Carl 136
Herschel, quotations from 182
Herschel, W. J., color photography 101
Hertwig, Richard, researches by 630
Hertz, H., demonstrates electric-wave theory 263
Hertzian-wave signals, first instance of 271
telegraphy 264, 268
Hewitt, J. N. B 53
Hill, R. T., accounts of Mont Pelée eruption 339, 348
Hillebrand, W. F., analyses of volcanic ejecta 348
Hippisley, Alfred E., ceramic art in China 104
Historical collections received by Museum 31
papers, list of 108
Hitchcock, C. H 114, 348
Hitchcock, Ethan Allen, member of Smithsonian Establishment ix, 2
Hitt, R. R., member of Museum building committee 3
Regent of the Institution x, 2, 4
Hobbs, W. H., emigrant diamonds in America 102
Hodge, F. W., report on international exchanges 58–72
Hodgkins fund xii, xvii, 6
grants for researches 7
publications under 100
Hodgkins special medal awarded to James Dewar 10
J. J. Thomson 11
Holdich, T. C., progress of geographical knowledge 351–373
Holmes, W. H 47, 48, 112
anthropological explorations by 21, 32, 35, 43, 104
on fossil human remains found near Lansing, Kans 455–462
primal shaping arts 102
Honduras, northern, mounds in 108
Hopi ceremonial pigments 104
Hough, Walter 32, 35, 102, 104
Hovey, E. O., on Martinique and St. Vincent eruptions 338, 348
Howard, L. O 96
Howes, G. B., the morphological method and recent progress in zoology 581–608
Hrdlicka, Ales 44
Huffaker, E. C 9, 140
Huggins, P. F., on Soufrière eruption 348

Page.
Huggins, Sir William, commends Astrophysical Observatory 4, 24
first spectroscopic study of nebula 155
researches in stellar temperature 159
Hull, G. F 180
Human breed, improvement of 102
Hummel, Charles, collections from 32
Humming birds, catalogue of 106
Hunter, John, researches in anatomy by 431
Hunterian oration, by N. C. Macnamara 431
Huxley, Professor 581, 628
on organization of brain 435
study of vertebrate skull by 595
Hybridization, Mendel's researches in 559
Hydrogen, boiling point of 218
liquid properties of, researches by Travers 10
researches in 174, 175
solid, by Dewar 101
stellar 158
Ichthyosaurs, morphological study of 590
Iddings, on origin of igneous rocks 304
Igneous magmas, consolidation of 294
rocks, solution theory 300
study of origin of 291
Illumination, development of 102
Illustrations, legislation governing lvi
Indian land cessions 108
languages, researches in 42
Territory, archæological collections from 32
ethnological discoveries in 21
Indian Territory, explorations in 43
tribes, cyclopedia of 21, 55
Indians, American, heraldic systems of 46
researches among 20, 39
Inheritance, phenomena of 559
Insects, collections received by National Museum 33
morphological study of 596
number of species of 582
papers on 106, 107
International Catalogue of Scientific Literature 15, 99
exchanges, appropriation for xix, liv, 6
curator's report on 58–72
exhibit at Buffalo 111
expenditures for xix
Secretary's report on 22
statistics of work of 58–72
Zoological Congress 17
Intestinal activity of bodies 411
Invertebrata, fossil, morphological study of 600
morphological study of 596
Ionized air researches by Barus 8, 100
Ionizing power of radium 199
Ions, size of 179
Irrigation, F. H. Newell on 102

Page.
Irrigation, in Egypt 531
J. W. Powell on 634, 638
Isomorphism, researches in 601
Israel, Oscar, life and work of Rudolph Virchow 641–659
Jaccaci, A. F., Pelée the destroyer 348
Jackson, Sheldon, reindeer brought to Alaska by 613, 619
Jacob, Georg, Oriental elements of culture in the Occident 509–529
Jaggar, T. A., on Martinique and St. Vincent 341, 348
Jakun tribes of Malay 463
Japanese art in the West 512
fishes, descriptions of 105, 106
Jarvis, David H 620, 623
Java skull, discussion of 437
Jenks, Albert E 41, 50, 56, 108
Jespersen's study of phonetics 258
Johnston, Sir H. H., pygmies of Great Congo Forest 479–491
the Okapi 103
Jones, William 43, 53
Jordan, David S., fishes received from 33
Jordan, David S., papers by 104, 105
Kathlamet texts, by Boas 108
Keeler's study of spiral nebula 156
Kelvin, Lord, commends Astrophysical Observatory 4, 24
ether and gravitational matter in infinite space 101
on fatigue of metals 407
researches with uranium rays 199
Kemp, J. F., earthquakes and volcanoes 348, 349
Kennan, George 339, 349
Kidder, J. H., bear skeleton from 32
Kidder fund xviii
Kinetic conception of molecular movements 407
King, Charles A 61
King, Clarence 303, 635
King crabs, zoological sequence of 601
Kirchoff, Alfred, the sea in the life of nations 102
Kites, observations at sea with 101
Knox, Philander C., member of Smithsonian Establishment ix, 2
Kodiak bear, in Zoologizal Park 23, 74, 76
skeleton of 32
König, Rudolph, sound studies by 246, 248
Korosy, Joseph von 62, 69
Kress, Herr, flying machine of 122
Kroeber, A. L 53
Kryton, rays of 232
Labels, Museum, importance of 18
Lacaze-Duthiers, H. de, study of coral by 610
Lachenaud, Georges 36
Lacroix, Professor, at Martinique 324
Lake dwellers, skulls of 444
Langley, S. P., accepts as trustee of Carnegie Institution 4
aerodrome designed by 122
aerodynamic experiments 100
cheapest form of light 100
fire-walk ceremony in Tahiti 102

Page.
Langley, S. P., "Good seeing" 193–195
greatest flying creature 103
laws of Nature 102
mechanical flight researches 7
personal-equation machine designed by 93
phenomena of sun spots 161
researches in solar radiation 165
Secretary's report to the Regents 1–115
Langmuir, A. C., literature of zirconium 100
Lansing man, Holmes on 455–462
post-Glacial 462
probable age of 461
skull, description of 456
Laplanders in Alaska 616
Lassimonne, S. E. 36
Lavoisier's researches in low temperature 211
Laws of Nature, by Langley 102
Lebaudy's balloon 122, 125
Lebedew, Peter, explanation of comets' tails 180
pressure of light 177, 178
Le Mesurier, E. A., letter from xiv
Lendenfeld, Dr. von, Hodgkins grant to 9
telephotography experiments 9
Lenses, improvements in 153
Lesseps, Ferdinand de 539
Levy, Michel, geological researches by 298
Librarian, report of 97–99
Libraries, publications distributed to 13
Library, accessions to 97
Secretary's report on 14
Library of Congress, Smithsonian deposit in 14, 98
Life of matter, Dastre on 393–429
phenomena, study of 628
Light, cheapest form of, by Langley 100
electro-magnetic theory of 180, 263
firefly, investigation of 96
magnetic theory of 177
photographic action of 237
pressure of 177, 178, 180
stellar, researches in 159
wave theory of 180
waves, velocity of 263
Lindsay, Senator xi
Linguistic evidence in racial problems 464
Liquefaction of gases, Dewar on 214
Liquid air 219, 220
effect on bacteria 239
carbonic acid 214
helium 221, 226
hydrogen 219, 221
properties of 221, 222
Travers's researches in 10
oxygen 219

Page.
Living and brute bodies, differences of 393
bodies and crystals 417, 422
matter, chemical composition of 403
origin of 399
Lockyer, Sir Norman, commends Astrophysical Observatory 24
theory of sun spots 171, 173
Lodge, O. J., wireless telegraph, tapper of 265
Loeb, Jacques, biological discoveries by 630, 632
Logograph, Barlow's 246
Long, John D., resignation of 2
Long, M. C 462
Lopp, W. T 620, 621
Louisiana Purchase Exposition 16, 38
Lovett, E 36
Low temperatures, electric properties of bodies at 237
researches in 207–240
Lucas, F. A., on Dinosaurs 103
flightless auk 105
Pterodactyl 103
Lyon, A. B 114
Lyon, Marcus Ward, jr 105
McDonald, T. M., at St. Vincent 313, 324
McGee, W J 44, 57, 108, 111, 349
McGregor, R. S 33
McGuire, J. D 51
McKee, S. S., Martinique disaster 349
McKinley, President, death of xi, 1, 2, 26
Macnamara, N. C., craniology of man and anthropoid apes 431–449
Macfayden, Professor, researches by 239
Magnetic properties of steel at low temperatures 237
Mahillon, Victor 36
Malay Peninsula, wild tribes of 463–478
Mammalogy, progress in study of 588
Mammals, development of 584
Mammoth teeth from Indian Territory 43
Manganese, bibliography of 12, 100
Man and apes, anatomical relations of 431
ape-like, in Africa 480
new type of 451
Lansing 455
Mentone 451
paleolithic 439
Map making, importance of 360
Marage's study of vowel sounds 256
Marconi, G., on wireless telegraphy 101
Marconi's tuned electric circuits 269
transmitting system 263, 266
Marey, Dr. J., chronophotography researches 9, 101
Hodgkins grant to 9
researches by 241, 245
Marine animals, preservation of 23, 103
Marine Biological Laboratory, work of 625–632
Marine university, by W. K. Gregory 625–632

Page.
Marriage customs of Malay tribes 474
Marsigli, study of coral by 609
Martin, Réné 36
Martin, Rudolf 463
Martinique, causes of death by volcano at 338
disaster, literature on 348
volcanic eruptions at (*see also* Mont Pelée) 309, 331–349
Mason, O. T 37
Aboriginal American harpoons 104
Directions for collecting basketry 107
Traps of American Indians 102
Mastodon remains, collected by Holmes 34
Mastodons, ancestors of 587
Material particles, migration of 411
Materialism, Virchow's attack on 649
Mathews, Albert 631
Matter, life of, by Dastre 393–429
transmission of 206
Matthews, E. O., collections by 32
Maver, William, jr., wireless telegraphy 261–274
Maxim, Sir Hiram 127
Maxwell-Lefroy, H., effect of volcanic dust on insects 349
Maxwell's researches on light 177
Mayan calendar systems 108
Means, Thomas H., the Nile reservoir dam at Assuân 531
Mearns, Edgar A 105, 107
Melville, George W., on submarine boat 103
Mendel, Gregor, experiments in hybridization 559, 563
Mendenhall, C. E 96
Mendenhall, T. C., commemoration of H. A. Rowland 103
Merriam, C. Hart, Bogoslof volcanoes 102
forest destruction 102
Merrill, A. A., wind researches by 10
Merrill, G. P 105, 107, 113
Metals, electric properties at low temperatures 238
fatigue of 407
movement of molecules of 414
Meteor, spectrum of 231
swarms, structure of 179
Meteorites, century of study of 101
collections in National Museum 34, 104, 105, 107
nebulæ and, discussion of 191
zodiacal light caused by 186
Meteorological researches by A. L. Rotch 10, 101
Mexico, archæological objects from 32
Micheli, M 36
Migration of material particles 411
Miller, Gerrit S 37, 107
Milne, J., volcanic eruptions in West Indies 349
Mindeleff, Cosmos 108
Mind of primitive man, by Boas 102
Mineral parentage and parentage of living beings 419
Minerals, order of consolidation of 292, 298

Page.
Minot, Charles L. 626
Model of nature, by Rücker 101
Mohr, Charles, plants bequeathed by 33
Moissan, Professor, researches by 236
Molecular movements, kinetic conception of 407
Mont Pelée, causes of death by eruption of 338
eruption of 325–329
literature on eruption of 348
volcanic material from 330, 336
Moody, William H., member of Smithsonian Establishment ix, 2
Moon, desolate character of 163
Mooney, James 42, 46, 55, 108
Morgan, T. H., biological studies by 629
Morphological method and progress in zoology 581–608
Mortillet, E. G. 444
Müller, Johannes 643
Music and dancing of Malay tribes 472
Musical instruments, collections received 31
scales, by C. K. Wead 104
Mutation theory of Prof. De Vries 103
Myths of the Cherokees 108
Napoleon Bonaparte, Watts de Peyster library on 15, 98
Naples zoological station 625
Smithsonian table at 11
National gallery of American art, proposed 17
National Museum, accessions to 29, 31
appropriations for xxii, liii, 6
assistant secretary's report on 29–38
building improvements 29
electric lighting of xxxiv
exhibit at Buffalo 112
expenditures for xxii
library of 15, 99
organization and staff 30
plans for new building liv, 19
publications 107
Regents' committee on new building for xii, 3
salaries of scientific staff 20
Secretary's report on 18
National physical laboratory 102
National Zoo at Washington, Ernest Thompson Seton on 103
National Zoological Park, accessions to 73
animals in 23, 78
appropriation for lv, 6, 73
exhibit at Buffalo 111
expenditures for xliv
Secretary's report on 23
superintendent's report 73–84
Native game, scarcity of 23
Nebulæ, meteorites and 191
spectroscopic examination of 155
spiral, Keeler's study of 156
temperature of 191

Page.
Negritos, height of 465
houses of 469
hunting and trapping by 468
origin of 463
Negro, origin of 482
pygmies of Africa 479
Nervous system, anatomy of 434
study of 629
Newcomb, Simon, commends Astrophysical Observatory 4
quoted 26, 180, 184, 186
Newell, F. H., on irrigation 102
Nicaragua, volcanoes in 556
Nichols, E. F 180
Nichols, stellar heat measured by 159
Nicobar Islands, collections from 31
Niewenglowski's experiments with radio-active matter 198
Nile reservoir dam at Assuân 531
Nucleus, structure of 8
Ober, F. A., a ruined American Eden 349
Oberholser, Harry C 106, 107
Observatories, list of 12, 100
Okapi, by Sir Harry H. Johnston 103
Olney, Richard, Regent of the Institution x, xi, 4
Orang, brain of 434
Oriental elements of culture in the Occident 509–529
Osborn, Professor, on Marine Biological Laboratory 625
Owen, Mary W., collections from 31
Page, James, range of volcanic dust 349
Paine, Albert Bigelow, children's room 102
Palace of Minos, by Evans 102
Paleobotany, collections in 34
Paleolithic man 438, 446
Paleontological collections in National Museum 34
Paleontology, progress in study of 583
Palmer, Edward 35
Palmer, William 32, 35
Panama Canal, commercial value of 557
construction statistics 554
feasibility of sea-level plan 544
original estimate for 540
Panama route for ship canal, by W. H. Burr 537–557
Pan-American Exposition, report on 110–115
Paper making, origin of 522, 523
Parel, G., Martinique disaster 349
Patagonia, explorations in 353
fossil animals in 586
Paulsen, Adam, study of northern lights by 188
Pawnee Indian ceremonies 43, 54
music and poetry of 21
Payne, Henry C., member of Smithsonian Establishment ix, 2
Penikese laboratory 626
Penrose, Senator, proposed national gallery of art 17
Perdew, George M., collection from 34

Page.
Permanent committee, report of xii
Personal-equation machine, design for 93
Petrological ideas, evolution of 287–308
Peyssonel, study of coral by 609, 610
Phalen, W. C., aid in Museum 31
Philip, Admiral J. W., swords of 31
Philippines, ethnological objects from 31
native tribes of 463
Phillips, O. P 43
Phonautograph, invention of 246
Phonetics, experimental 241–259
Phonograph, development of 246
improvements in 251
records, collection of 258
Edison's 32
Phosphorescent bodies luminous when excited 205
Photographic action of light 237
Photographs, astronomical, improvements in 152
by uranium rays 198
sound waves 249
Photography, color 101, 415
Phototopography, importance of 369
Physical ethnology, researches in 39
laboratory, National 102
Physico-chemical speculations as to rocks 303
Physiology, comparative 628
Pickering, E. C 4, 231
Pictet and Cailletet, low temperature researches by 217, 220
Pilcher's flying machine 135, 136
Pinchot, Gifford, forest destruction 102
Pithecanthropus erectus, discussion of 437, 438
Plants, laws of heredity in 563
Platt, O. H., member of Museum building committee 3
Regent of the Institution x, xi, 4
Plumacher, E. H 75
Polar streamers of the sun 160
Pollard, C. L 35
Polonium, radio-activity of 200
Poppoff's wireless telegraph apparatus 265
Porto Rico, birds from 32
ethnological researches in 21, 42
Powell, John Wesley, biography by G. K. Gilbert 633–640
director of Bureau of Ethnology 21, 108
ethnological work of 41, 635, 637
Poynting, John H., on gravitation 101
Preece, William H., wireless telegraph experiments by 262
Prehistoric archaeology, Virchow's studies of 655
man in Europe 431
France 102, 452
Kansas 455
Prentiss, C. W., at Smithsonian Naples Table 11
Pressure of light, investigation of 177
Primal shaping arts, Holmes on 102

Page.
Primitive man in Europe 441
Prince of Monaco, explorations by 451
Printing, appropriation for Museum 6
Problems of heredity and their solution 559–580
Protoplasm, crushed, vital phenomena in 404
Huxley on 628
in continuing substance 424
Psychology, studies in 44
Pterodactyl Ornithostoma, by Lucas 103
Publications, Astrophysical Observatory 85
Bureau of Ethnology 56, 108
editor's report on 100–109
National Museum 37, 107
Secretary's report on 12–14
Pygmies of Great Congo Forest 479–491
Herodotus 483
Radiations, cathode and Röntgen rays 101
Cuban firefly 96
solar 86, 177, 235
spontaneity of 206
stellar, measurement of 159
Radio-activity of Matter, by Becquerel 197–206
Radium, chemical reactions caused by 199
discovery of 199
ionizing power of 199
penetrating rays from 204
properties of radio-activity of 200
radio-active at lowest temperatures 237
spectrum of 199
spontaneous growth of 206
three kinds of rays from 200
transference of radio-activity 205
Ramsey, William 10
Rathbun, Mary J., on Decapod crustaceans 107
Rathbun, Richard iii
assistant secretary ix
report on National Museum 29–38
Ravenel, W. de C., appointed administrative assistant 31
Rayleigh, Lord, commends Astrophysical Observatory 4, 25
researches by 229
Regents, organization of Board in 1902 4
proceedings of meeting of xi–xvi, 2, 101
Reid, S. C., St. Vincent catastrophe 349
Reindeer in Alaska, by Gilbert H. Grosvenor 613–623
Religion of Malay tribes 477
Religious ideas from the Orient 509
Renard's air ship 125
Reptiles, fossil, progress in study of 589
Research, Secretary's report on 7
Rhees, William J 32
Richards, James E., at St. Vincent 316
Richmond, C. W 105, 107
Ridgway, Robert 37, 107

Page.
Ritchey's astronomical photographs 153
Rivière, Emile 102, 451
Roberts-Austen, W 394
Robinson, Wirt 105
Rocky Mountain sheep in zoological park 23, 76
Röntgen rays, by Dastre 101
Roosevelt, Theodore, member of Smithsonian Establishment ix, xi, 1, 2
Regent of the Institution x
Root, Elihu, member of Smithsonian Establishment ix, 2
Rose, J. N 33
Rosenstock, Edward 36
Rotch, A. Lawrence, meteorological researches by 10, 101
Roule, Louis, natural history of coral 609–612
Rowland, Henry A., memorial of 103
Royce, C. C., Indian land cessions 108
Rücker, Arthur W., model of nature 101
Russell, Frank 42, 44
Russell, Israel C., volcanic eruptions on Martinique and St. Vincent 331–349
Rutherford, Mr., researches by 199
Safford, W. E., Abbott collection from Andaman Islands 102
Guam and its people 493–508
St. Clair, H. H 42, 52
St. Pierre City, causes of death at 338
destruction of 325
St. Vincent, volcanic eruption on 309–330, 331–349
Saki tribes of Malay 463, 465
Salisbury, R. D 455, 458
Salt and its physiological uses 103
Santa Fe Palace xv
Santos-Dumont's navigable balloons 103, 122, 124
Schaus, William 33, 106
Schellwien, E 36
Schirmer, C 36
Schliemann, Heinrich, explorations by 656
Schuchert, Charles 34, 35
Schumann, Victor, Hodgkins grant to 8
spectrum researches by 8
Schwarz, E. A., insects presented by 33, 35
Scorpions, morphological study of 606
Scott, E. S., the eruption of Mont Pelée 349
Scott, Leon, phonautograph of 246
Scripture, Professor, investigation of vowel sounds 252
Sea in the life of nations 102
Sea urchins, life history of 631
Seibold, L., destruction of St. Pierre 349
Semang tribes of Malay 463, 465
Seton, Ernest Thompson 32, 103
Severo's balloon 122
Shaler, N. S., nature of volcanoes 349
Shaw, Leslie M., member of Smithsonian Establishment ix, 2
Shönlein, Johann Lenkas 644
Siberia, reindeer brought to Alaska from 613
Sidebottom, H 36
Sindo, Michitaro, on Japanese fishes 106

Page.
Skeat, W. W., wild tribes of Malay 463–478
Skulls from French caves 453
of man and apes, relation of 432
paleolithic 439, 440
vertebrate, Howes on development of 595
Smith, A. Donaldson 32
Smith, Charles Emory, resignation of 2
Smith, Longfield, West Indian volcanoes 349
Smithson, James, bequest, amount of xvii, 6
personal relics of 111
proposed removal of remains of xiv, 3
Smithsonian Art Gallery 17, 98
Smithsonian deposit in Library of Congress 14
Smithsonian Institution, article on work of 101
exhibit at Buffalo 110
finances of xvii–li, 5–7
foreign agents of 68
meeting of Regents xi, 2
members of Establishment 2
organization of Board of Regents 4
publications by 12, 100
Secretary's report on 1–115
Smithsonian Report, popularity of 13
Snyder, J. O., papers by 104, 105, 106, 107
Soaring flight, Wright on 147
Solar atmosphere, study of 165
energy, spectrum 86
study of 25
envelope, absorption by 86, 90, 165
changes in density of 166
transparency of 91
image, great, provision for 94
improvements in securing 26
phenomena, periodicity of 169
radiations, investigations in 86
pressure of 177
researches in 235
researches at Astrophysical Observatory 25
spectra, discovery of meaning of 151
temperature, variations in 171
theory, a new, by Halm 165–176
Solid hydrogen, by Dewar 101
Soufrière, eruption of, report by Anderson and Flett 309–330
literature on eruption of 348
products of eruption of 316, 336, 343
Sound, vocal, researches in 9–243
waves, experiments with 268
South America, explorations in 358
Spectroscope, absorption of 87
literature of 12, 100
Spectroscopic examination of nebula 155
Spectra, of gases 232
solar, discovery of meaning of 151
star 158

Page
Spectrum, corona 234
meteor, by Pickering 231
researches by Schumann 8
solar, researches in 25
energy, study of 86
zodiacal light 186
Speech, record of acts of 242
Spencer, Stanley, ballooning by 122
Spontaneous generation 400, 423
Sprague bequest xii
Spratt, G. A 141
Stanton, Timothy W 106
Starin, J. H 75
Starks, Edwin Chapin 105
Stars, changes in color of 162
development of 154
red, phenomena of 162
Stassano, Henri, on aurora rays 232
Stead, J. E., researches by 298
Steam motors, improvements in 133
Stearns, R. E. C., fossil shells 106
Steere, J. B 33
Stein, Robert 31, 33, 43
Steiner, Roland B., collections by 32
Stejneger, Leonhard 17, 105
Stellar evolution in light of recent research, by George E. Hale 149–163
heat, Halm on 166
temperatures 159
Stevenson, Matilda Coxe 55
Stokes, Sir George, commends Astrophysical Observatory 4, 25, 85
Stoney, Johnstone 222
Submarine boat, by Melville 103
Sun, and its radiations, researches in 25
chemical composition of 151, 161
chromosphere, study of 161
corona of, Hale on 160
dimensions of 160
disk, study of 161
electric discharges in atmosphere of 235
energy, utilizing, by Thurston 101
envelope, absorption of 91
gases in 174
polar streamers, study of 160
prominences and corona 160, 184, 185
Sun spots, periodicity of 161, 169, 188
relation of solar radiation to 25
relation of, to aurora 188
study of 161
temperature, variations in 171
Sunlight, pressure of 180
Swanton, John R 42, 52
Swiss lake dwellers 443
Sylvestri, Felippe 36

Page.
Tait thermo-electric diagram 238
Talbot, Henry P., bibliography of manganese 100
Tassin, Wirt, gems in National Museum 104
meteorites in National Museum 104
Taylor, C. P., Martinique disaster 349
Teall, J. J. Harris, evolution of petrological ideas 287–308
Telegraphy, harmonic multiple 32
wireless, by Marconi 101
Maver on 261–274
Telephone devices, collection of 32
Telephoning, trans-Atlantic, by Anthony 101
Telephonograph, by Hammer 101
Telephotography experiments by von Lendenfeld 9
Telescopes, improvements in 154
Yerkes Observatory 151
Telescopic image, "boiling" of 95, 193
Telpherage, apparatus for 276–286
commercial uses of 275–286
Telphers, construction of 279
Temperature, bolometer measurements of 25
low, effect on living organisms 239
researches in 207–240
nebulæ 191
of rock crystallization 296
pressure and volume, relation of 216
solar, variations in 171
star, measurement of 159–167
terrestrial, study of 25
upper atmosphere 230
zero of 211
Texas, manuscript history of 55
Thermometers, experiments with 40
Thiele, J 36
Thomas, Cyrus 54, 108
Thomas, Jessie E 53
Thompson, Edward H 53
Thompson, William, on Irish fauna 608
Thomson, James, researches by 216
Thomson, J. J., bodies smaller than atoms 101, 179
Hodgkins special medal awarded to 11
researches by 199
Thorium rays, study of 199, 205
Thurston, Robert H., utilizing sun's energy 101
Tibet, need of explorations in 344
Tindall, Marcus, where the earth's crust is weak 349
Totemism, American Indian 47
Trans-Atlantic telephoning 101
Transition from brute to living bodies 395
Transmission of matter 206
Traps of American Indians 102
Travers, Morris W., Hodgkins grant to 10
researches by 10
Triceratops, restoration of 114

Page.
Troost, M., researches by 198
True, F. W 16, 35, 38
report on Buffalo Exposition 110–115
Trumbull, James Hammond 54
Tuckerman, Alfred, Literature of Spectroscope 100
Turner, George B., chief taxidermist 31
Türr, Gen. Etienne 538
Tusayan clans 108
Ulrich, E. O 34
Upham, Warren 458
Upper air and auroras, Dewar on 229
Uranium rays, early experiments with 197
Van der Waals, researches by 174, 216
Varian's sketch of Mont Pelée eruption 334
Verneau, M., new human type 451
Verrill, A. E., on causes of death at Martinique 349
Very, F. W., cheapest form of light 100
Vibrations, method of recording 251
Villard, M., study of radium rays 200
Villeneuve, M. de, discoveries by 452
Virchow, Rudolph, Israel on life and work of 641–659
Vital activity and activity of particles 407
force, doctrine of 649
Vocal sounds, researches in 241
Vogt, Karl 649
Volcanic action, theories of 348
bombs from Mont Pelée 337
from Soufrière 316
dust and sand from the Soufrière 317
range of 349
eruptions in Antilles, literature of 348
eruptions on Martinique and St. Vincent, by Russell 331–349
on St. Vincent, by Anderson and Flett 309–330
material from the Soufrière crater 316
rocks, study of 301
Volcano, Chemnitz 304
Volcanoes, Bogoslof, in Alaska 102
explosive force of 348
Isthmus of Panama 556
nature of 349
Nicaragua 556
West Indian, report by Anderson and Flett on 309–330
Von Bezold on compass variation 190
Von Lippmann, Edmund O 520
Vowels, nature of, researches in 9
Vowel sounds, studies of 246–252
Voy, C. D 34
Walcott, Charles D 34
Walker, Gilbert T., on boomerangs 102
Walker, W. G 122, 126
Wallace, Alfred Russell 465
Warmsley, W. C., collection from 31
Washington, George Fayette 31

Page.
Water buffalo 103
vapor, absorption of 88
Watts de Peyster collection, Napoleon Bonaparte 15, 98
Wead, C. K., musical scales 104
Wells, H. G., discovery of the future 375–392
Wesley, William, & Son 62, 69
White, Andrew D., Regent of the Institution x, 4
White, Charles A., mutation theory of Professor de Vries 103
White, David 34, 106
Whitman, C. O 626
Wiechmann, F. G., volcanic dust 349
Wild rice gatherers of Upper Lakes 50, 108
Wild tribes of Malay Peninsula 463, 478
Willcocks, W., on Nile reservoir 532
Willey, D. A., erection of Gokteik bridge 103
Williams, John C 61
Williston, S. W., on Lansing remains 455, 458
Wilson, Edmund B 630, 632
Wilson, H. V 33
Wilson, James, member of Smithsonian Establishment ix, 2
Wilson, Thomas, death of 27, 30
Wilson, W. L., resolutions in memory of xi
Winchell, N. H., on Lansing remains 455, 458
Wind, lift and drift of, Rotch researches 10
velocities of 9
Wire telegraphy, Gray's harmonic system of 270
Wireless telegraphy, apparatus for 264
commercial use of 273
Henry's experiments with 262
Marconi's experiments 101, 267
Maver on 261–274
Preece's experiments 262
Wolfer, Professor, quoted 171
Wood, Herbert S 56
Woods Hole, marine university at 625–632
Worcester, Dean C 33
Wright, Orville, aeronautical experiments by 133
Wright, Wilbur, gliding-machine experiments 122, 126
some aeronautical experiments 133–148
Wyse, L. N. B 538
Yellowstone National Park, animals from 75
Yerkes Observatory, astrophysial instruments at 151
Young, John L 75
Young's theory of the Corona 185
Zeppelin's airship 121, 125
Zodiacal light, nature of 185
Zoological Congress, International 17
parks, by Aflalo 103
Zoology, recent progress in, by Howes 581–608

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